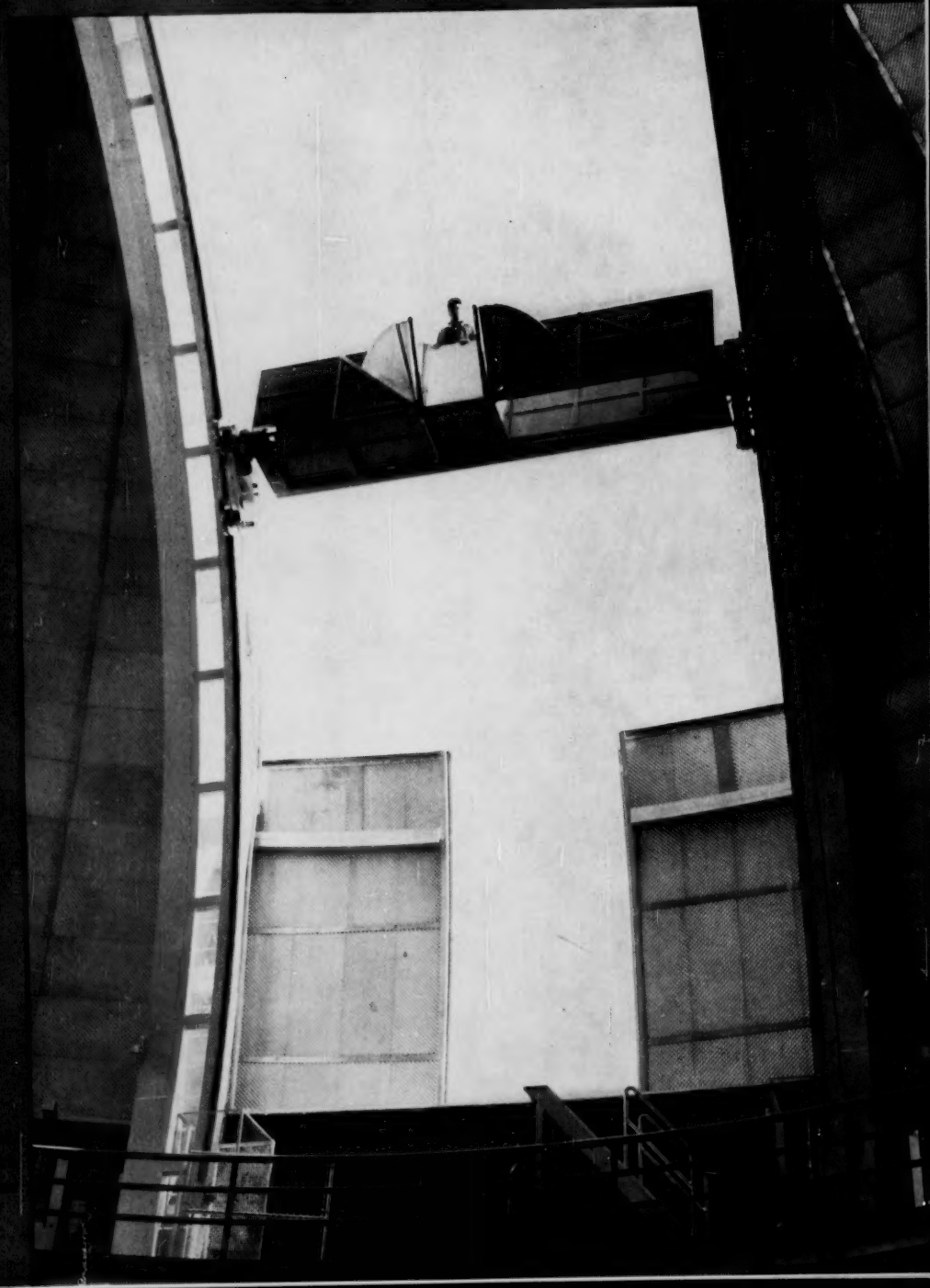
Sky and Telescope



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Lick Observatory 120-inch Album

Some Photoelectric Problems

Sky and Telescope

Northern and Southern Star Charts

Vol. XIV, No. 3

MARCH, 1955

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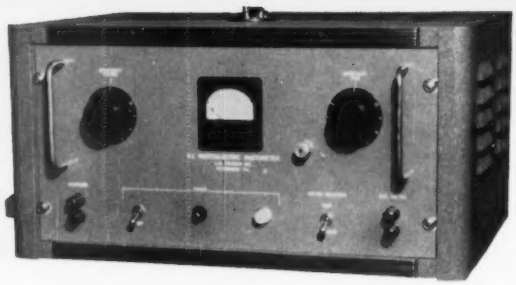
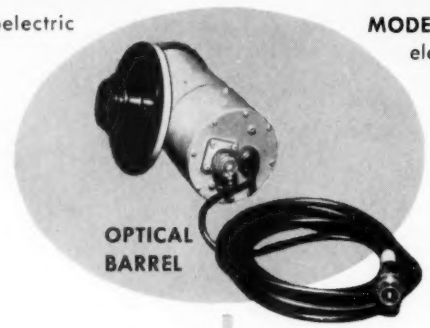
POWERFUL TOOLS for ASTRONOMICAL PHOTOMETRY



MODEL II. Direct Current Photoelectric Photometer A.C. Operated.

This instrument is intended to be used directly from any local power line outlet providing 60 cycle A. C. voltage between 109 VAC and 125 VAC. Complete in two units, the Optical Barrel and Amplifier.

In Model II zero-drift has been eliminated to such an extent that it does not exist within the operating limits.



Fabricated from lightweight aluminum. Complete with light orifice, 1P21 photomultiplier tube, cell, dry-ice chamber, insulation, dynode voltage divider, high voltage co-axial cable, and signal cable connector.

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Requires no external source of electric power for operation. All necessary power supplied by self-contained batteries. Complete in two units, the Optical Barrel and Amplifier.

Particularly versatile for portable applications where the telescope may be operated away from a source of electric power.

Here are two highly stable and sensitive electronic light meters reading relative stellar magnitudes. Both amplifiers are of the direct current type, balanced, with the voltage comparator characterized by simplicity. Both units exhibit high linearity on all ranges and insensitivity to stellar scintillation. The Model II is noted for low power requirements. The Model III has no external power requirements.

The sensitivity of both photometers is adequate for use on an instrument as small as a six inch reflector. The two co-axial cables leading to the Optical Barrel are extremely light in weight, minimizing the necessity for counterweighting and making it possible to use the instruments even on very lightweight telescopes.

Both the Model II and Model III are designed to be used on all types of telescopes, either permanently mounted or portable.

For complete information write for Bulletin No. 155.

j. w. fecker, inc.

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Sky and TELESCOPE

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COVER: A view through the lower part of the slit in the 96-foot dome of the 120-inch reflector at Lick Observatory, Mt. Hamilton, Calif. The main part of the shutter has been opened upward over the back of the dome; the lower sections are 17 feet high and are seen partly opened. To gain access to the prime-focus cage at the upper end of the telescope tube, an observer rides the slit elevator or platform, which is here seen partway up the slit. Safety wings protect the observer as he steps through the door of this platform to the cage. Lick Observatory photograph, taken April 3, 1952, by J. F. Chappell. (See page 176.)

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A Trip to Mt. Hamilton

LICK OBSERVATORY is reached by an air traveler by bus from San Francisco airport to San Jose. Then, unless he is met by someone from the observatory who has driven down 19 miles of the windingest road in the West, he takes the daily mail stage to Mt. Hamilton. On a day shortly before Christmas, 1954, this editor arrived in San Jose at a very early hour, but missed the stage because of a change in schedule for the heavy Christmas mail.

Dr. C. D. Shane is director at Lick, and Mrs. Shane happened to be in town on a shopping trip that day. She fortunately decided to investigate a rumor that had drifted up the mountain—"a bald-headed foreigner with two suitcases" was waiting at the post office. Thanks to Mrs. Shane, I reached the mountaintop in time to see the sun's last rays bathe the massive silvery dome of the 120-inch, with the upper part of the telescope tube showing bright yellow through the partly opened slit. The fork of the mounting is painted an olive brown, and the declination disks are a terra-cotta red.

December weather at Lick is not supposed to be good, but skies were clear during practically all of my four-day stay. I was given ample opportunity to explore the instruments and buildings. There is great activity on the mountain, new residences and a library have been built, and there is much planning for observations with the big reflector now nearing completion.

The painting of the mounting and tube in December marked the practical completion of the construction of those parts contracted for by Judson Pacific-Murphy Corporation. Although the optics for the auxiliary equipment are well under way, the primary mirror is still a major project that may require a year to complete.

Through the courtesy of Dr. Shane, we present in this issue of *Sky and Telescope* a brief account of the 120-inch project, and the first part of an album telling the story from the time of ground breaking in January, 1950, to the present.

The album will appear in several parts. It is a selection from the extensive set of pictures taken by the Lick photographer, J. F. Chappell, with supplementary photographs by W. W. Baustian, engineer in charge of the 120-inch project. Mr. Chappell prepared the prints from which the engravings were made, and Mr. Baustian supplied detailed information for the picture captions.

C. A. F.

The Lick 120-inch Reflector

FAMOUS among the telescopes of the world are the two 36-inch instruments of Lick Observatory of the University of California. One of these is a refractor, built by Warner and Swasey in 1888, with optics by Alvan Clark. For a decade it was the largest refracting telescope in the world, and is still exceeded only by the Yerkes 40-inch refractor. It is in regular use on a variety of programs that may be effectively carried out in a restricted color range, with long focal length and excellent observing conditions.

The other is the Crossley reflector, the mirror of which was made in London in 1879 by Dr. A. A. Common, and presented to Lick Observatory in 1895. This versatile instrument operates regularly for direct photography, spectroscopy, and photoelectric photometry of the fainter stars and brighter nebulae.

At Lick, where the emphasis is on observational astronomy, these instruments are in constant use. But the need has long been felt for a larger telescope that can gather many times more light than a 36-inch aperture. Both W. W. Campbell, director from 1901 to 1930, and R. G. Aitken, his successor from 1930 to 1935, were anxious to obtain funds for a large reflector. In the later 1930's, Director W. H. Wright and his staff proposed a large instrument as part of an extensive building program envisaged by President R. G. Sproul, of the University of California. Dr. J. H. Moore, director from 1942 to 1945, was a strong backer of the project, but little progress was possible during World War II.

Near the close of the war, Dr. Moore retired and C. D. Shane, professor of astrophysics in the Berkeley department of astronomy, left his wartime position as director of personnel at Los Alamos Scientific Laboratory to assume the leadership at Mt. Hamilton. For the new telescope project, an advisory committee was set up, consisting of three astronomers from Mount Wilson and Palomar Observatories, including Director W. S. Adams, and three Lick astronomers.

Plans were drawn for an instrument somewhere in size between the 100-inch and the 200-inch, its cost not to exceed a million dollars. In this size range, it was felt that much costly experimental engineering could be avoided, and standard practice and components utilized. Experienced Mount Wilson observers greatly influenced the committee's recommendation that a 120-inch f/5 reflector would be the most effective instrument for Lick Observatory.

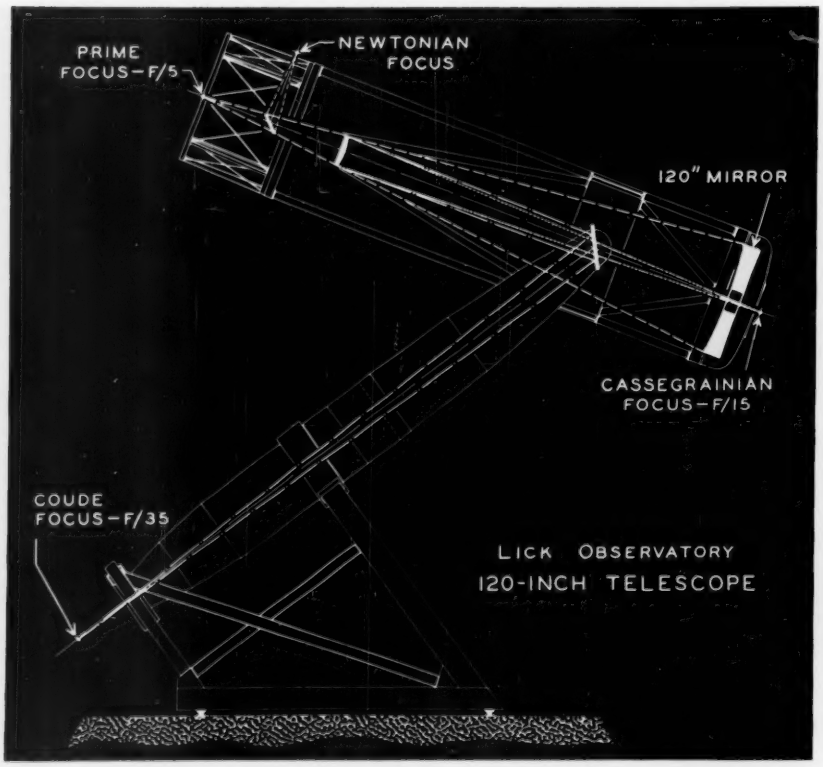
The telescope was included in the University of California budget submitted to the state legislature late in 1945, and early the next year Drs. Shane and N. U. Mayall went to Sacramento to give details concerning the project to a legislative committee reviewing the budget.

For a time the future of the telescope looked rather uncertain. Finally, on March 13, 1946, Governor Earl Warren signed an appropriation bill that included $900,000 for Lick's new instrument. This was afterwards increased several times, to $1,800,000. Additional appropriations by the regents of the university and the state of California bring the total budget for the telescope and instrumentation to approximately 2½ million dollars.

W. W. Baustian, an engineer from California Institute of Technology, was engaged as engineer in charge of design and construction of the building and instrument. The optical work was placed in the hands of D. O. Hendrix, of the Mount Wilson optical shop, well known for his work on the 48-inch Palomar Schmidt telescope. All optical processing of the 120-inch disk and secondary mirrors is being carried on at Lick Observatory, in an optical shop located in the basement of the building for the large reflector.

Procuring a solid pyrex disk 120 inches in diameter was the next major problem. Up to 1948, it was still not known just how well the ribbed 200-inch mirror would actually perform; therefore, a 120-inch ribbed disk previously cast to test the 200-inch mirror was not considered at first. In England, the firm of Pilkington Brothers was interested in providing a 100-inch disk for the Isaac Newton telescope at the Royal Greenwich Observatory, and from this experience they hoped to be able to make a 120-inch blank. In addition, a tentative quotation was received from Corning Glass Works.

About 1949 the 200-inch came into operation, and showed that problems of the ribbed mirror had been overcome by a suitable supporting system. Therefore, the Lick astronomers decided to pur-



The 120-inch reflector design provides for four focal points, as this sketch of its optical arrangements shows.

chase the 120-inch ribbed blank from Caltech, for the modest sum of $50,000. Four secondary disks, two of them 50 inches in diameter, were bought from Pilkington Brothers, and later four disks were procured from Corning.

Chiefly because of the weight of the contemplated solid primary mirror, the mounting point of the declination axis was set one quarter of the way up the skeleton tube. In the large fork mounting, this gives ample clearance for any kind of Cassegrainian spectrograph or other device. The Cassegrainian hole in the mirror is eight inches in diameter. When the telescope first comes into operation, however, the Cassegrainian focus will not be used; all observations will be made at the prime focus or in the coude room at the south end of the polar axis.

The 120-inch mirror is a conventional paraboloidal reflector, with a focal length of 50 feet. The plate scale at the prime focus will be 13.5 seconds of arc per millimeter, nearly three times the scale of the Crossley reflector.

This is the 120-inch dome as it appeared on a December morning in 1954.

It is this large plate scale, together with a light-gathering power 1½ times that of the 100-inch telescope, that has the Lick astronomers anxiously awaiting the day when they can observe the fainter stars, galactic nebulae, and galaxies with the 120-inch. Dr. Mayall will work on the brighter resolved parts of the nearer galaxies, observing their globular clusters, emission patches, brighter stars, and variable stars, with a prime-focus spectrograph. He will study the rotations of elliptical galaxies and early-type spirals, by measuring the inclinations of their spectral lines when the slit is placed lengthwise on such an object. Hitherto, the scale of the Crossley has been rather small for such observations, and the f/19 refractor too slow.

Dr. Shane has for many years been engaged in counts of galaxies with the 20-inch astrographic telescope (see *Sky and Telescope*, August, 1954). With the new reflector he hopes by direct photography to get sample counts of faint galaxies, probably to the 22nd magnitude.

Photoelectric astronomers G. E. Kron and O. J. Eggen expect to use highly sensitive cells at the prime focus, where the maximum amount of light will be insured by only one reflection—that of the primary mirror. In the southeast part of the observatory building there is a room in which the photoelectric recording apparatus will be permanently installed. The observer in the prime-focus cage will always have an assistant in that room, with telephonic communication.

In the photoelectric work there will probably be heavy emphasis on the infrared, and six-color studies will be carried out on galactic clusters. Photoelectric observations will be made of individual stars and star clusters in the nearer galaxies, M31 and M33. The great light-gathering power may permit photoelectric work on bright individual objects out as far as the Virgo cluster. The magnitude limit for a 1P21 photocell on the 120-inch will be of the order of 21½.

For the coude focus, a versatile spectrograph for high and medium dispersion will be constructed according to optical designs by Dr. George Herbig. He and Dr. W. P. Bidelman will use this instrument principally in extensive detailed studies of stellar spectra of all types. It is anticipated that the spectrographic material speedily accumulated by this instrument will be of value to other astronomers as well. At the prime focus, a spectrograph of moderate dispersion (100 angstroms per millimeter) will enable Dr. Bidelman to measure radial velocities of faint variable stars in the Milky Way galaxy and to classify the spectra of faint stars. These studies will aid general research on galactic structure.

Throughout the whole 120-inch project there has been close co-operation with Mount Wilson and Palomar astronomers. Their experience was invaluable in design and construction problems. This co-operation will also extend to observing programs, which will be closely co-ordinated to avoid duplication and to ensure that the different instruments in California will be used to best advantage in the solution of astronomical problems.

At the end of last year, the 10-foot mirror was resting on the grinding machine, covered with plywood boards for protection. It had been fine ground nearly to its edge.

This is the site of the new telescope, as it appeared in the fall of 1949. The house was moved about 300 feet, and the tennis court was demolished. Beyond the house may be seen Copernicus Peak with its forest service lookout tower. Farther right, topped by a water tank, is Kepler Peak.

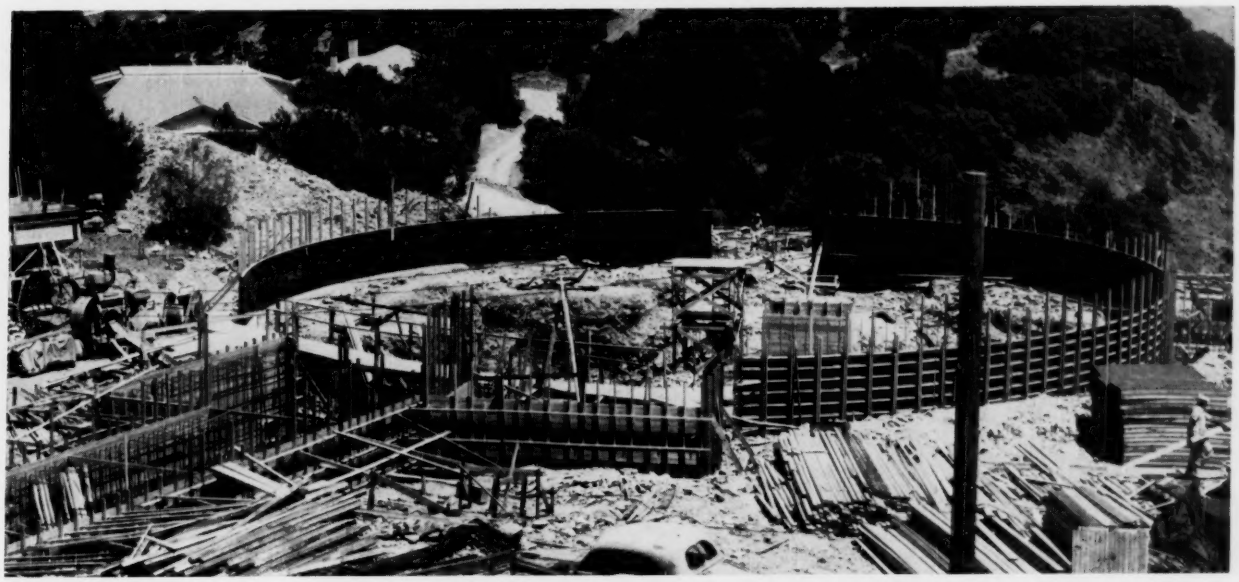
Lick Observatory

120-INCH ALBUM

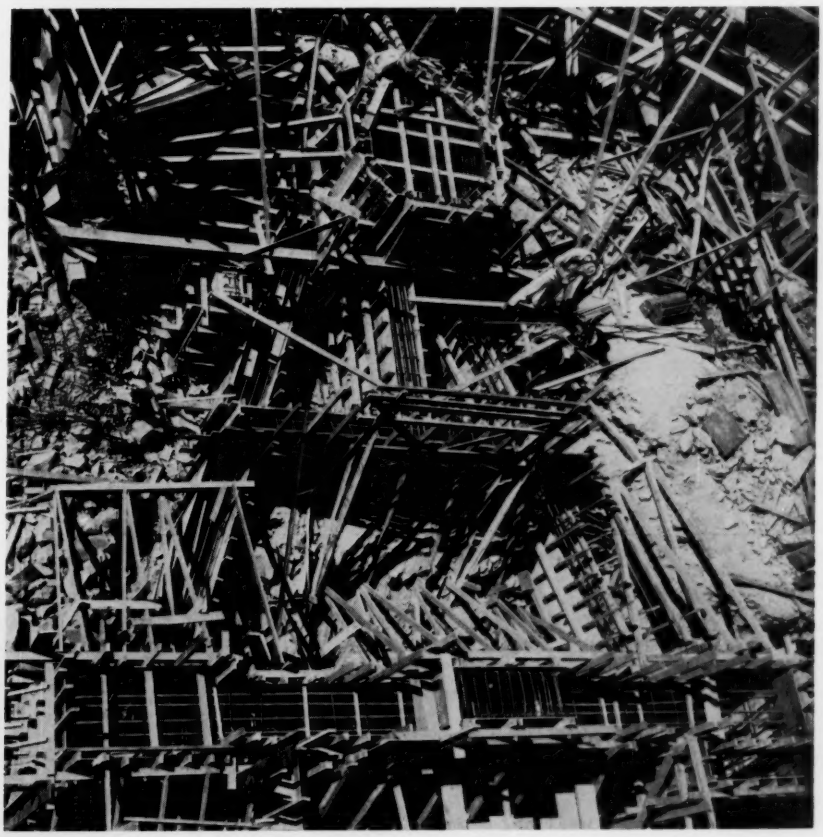
J. F. CHAPPELL
AND W. W. BAUSTIAN
Lick Observatory
University of California

Above: February 6, 1950. The site has been cleared and bulldozed, and excavation for the testing tunnel has begun. The drill rig is starting to sink the holes for the concrete pilings under the telescope foundations (for which the forms are shown in one photograph of July 27, 1950).

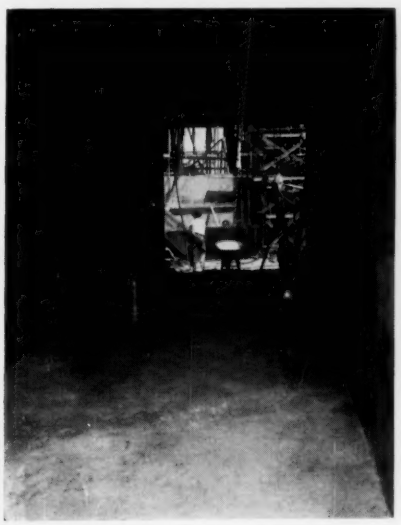
Right: April 4, 1950. The excavation for the testing tunnel can be seen on the right, and for the coude room at the far left. Visible in the left foreground is part of the circular trench for the foundation of the main walls of the building. The house at the right is the one that was moved from the site. In this view toward the southwest, the dome of the 20-inch astrographic telescope is prominent.



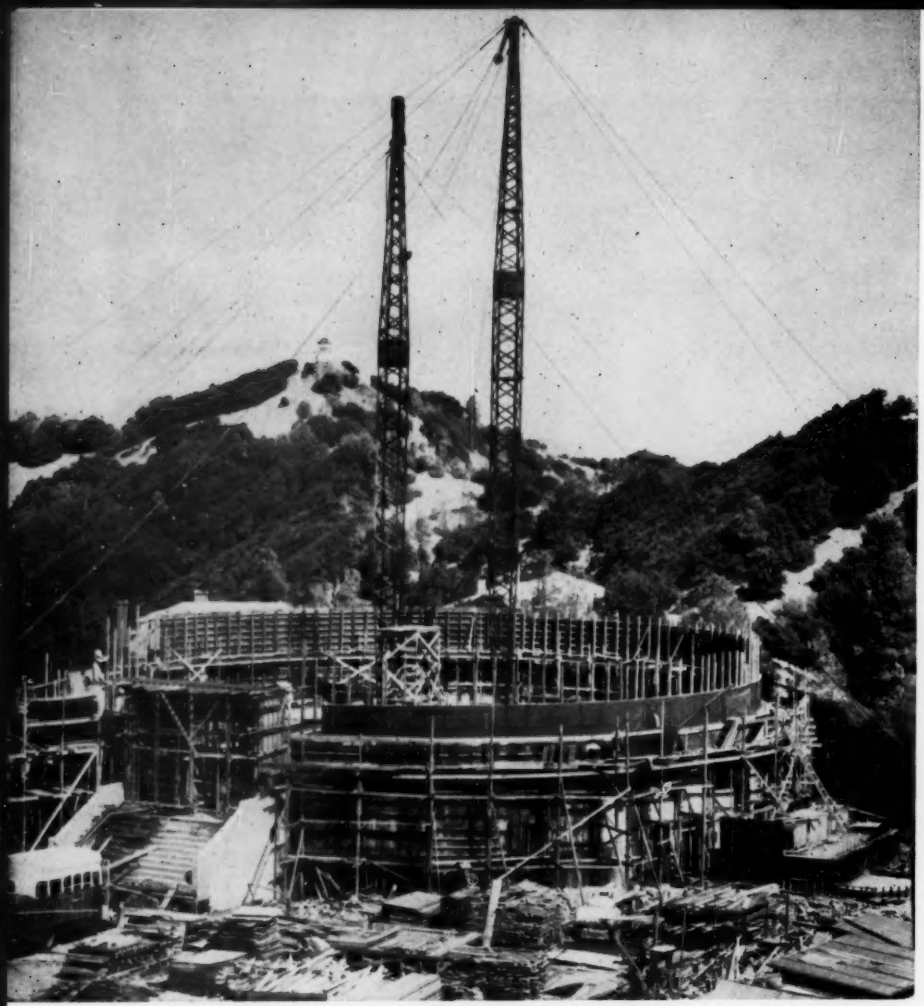
Above: May 23, 1950. The concrete forms for the walls of the building now begin to take shape. The break in the foreground is for the entrance way; that in the far (eastern) side is for the huge utility entrance, through which all parts of the telescope will later pass. Note in the lower left the forms for the testing tunnel, which will be completely underground.



Below: July 27, 1950. Along its length the testing tunnel tapers from 12 feet wide at the building wall (toward which we are looking) to 10 feet wide at the outer end. Its height is 11½ feet. The tunnel extends 74 feet outside the building.



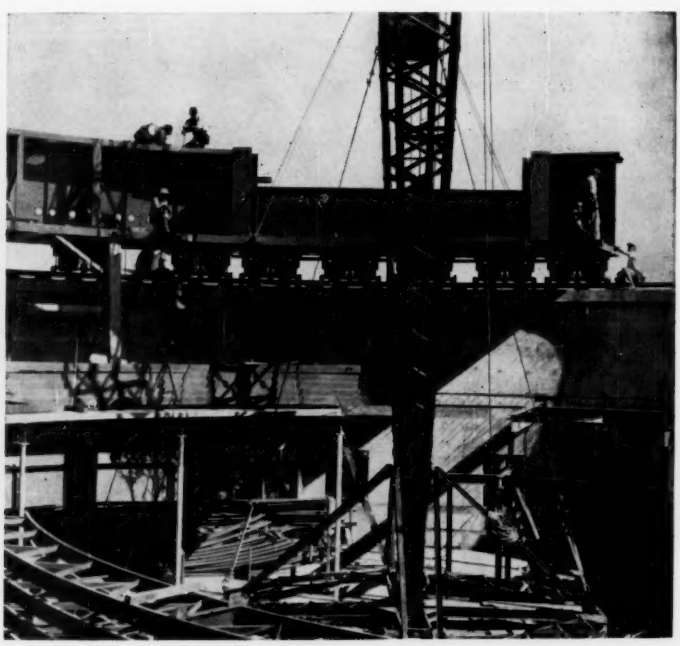
July 27, 1950. In this picture we are looking down on the interior dome area, seeing the formwork for the foundations that will bear the weight of the massive instrument. The octagonal south pier support is at the top, right of center; the north piers are at the right and left foreground. All three are connected by reinforced beams, forming a triangular structure below the level of the ground floor. At the bottom, right of center, the raised portion of the beam connecting the two north piers is the shear column providing for east-west positioning of the mounting. Two thirds of the east-west horizontal seismic shear will be taken by this column, the remainder borne by the ball-and-socket support at the south pier. The south pier will take all north-south seismic shear.



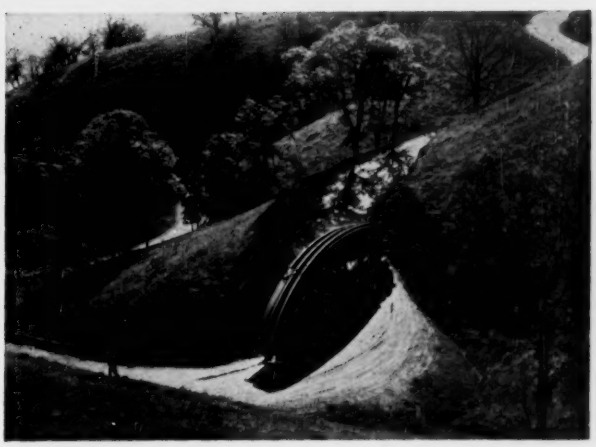
Left: October 4, 1950. As the walls of the building rise higher, its great size becomes more apparent. The final building and dome dimensions will be 96 feet in diameter and 94 feet high. The building contractor is Carrico and Gautier, of San Francisco. In this picture, the front entrance steps have been completed, as well as the walls and part of the ceiling of the coude spectrograph room, the interior of which is shown in one of the photographs of April 3, 1952.

Below left: December 15, 1950. The concrete wall that will support the revolving dome is complete, and the track for the dome is laid. The shelf projecting from the inside of the wall will support one of the three dome drive units.

Below right: April 10, 1951. The lowest section of the dome is a very heavy ring girder. It is supported by the trucks on the track. Behind the derrick is the section at the base of the slit opening. Because the main arch girders run alongside the slit, the weight to be supported here is greatest, requiring close spacing of the trucks alongside of and under the slit opening.

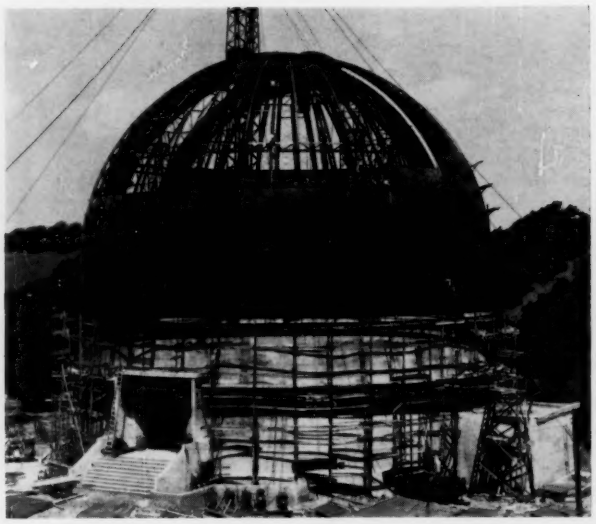


Above: April 27, 1951. A crucial operation in the erection of the dome was the assembly of the first main arch girder. There will be two of these, one on each side of the slit opening. The skeleton towers supported the end sections of the arch until its center portion was installed. Now a rib of the dome is being hoisted into place. The arch girders are each five feet deep, of ½-inch steel, with 18-inch-wide flanges at top and bottom.

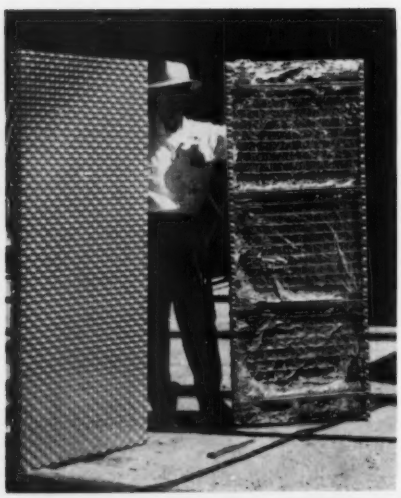


Right: April 20, 1951. Sections of the arch girders are being trucked up the winding Mt. Hamilton road. Difficult turns often had to be negotiated by backing. One truck stalled for several hours, blocking completely all traffic up the mountain.

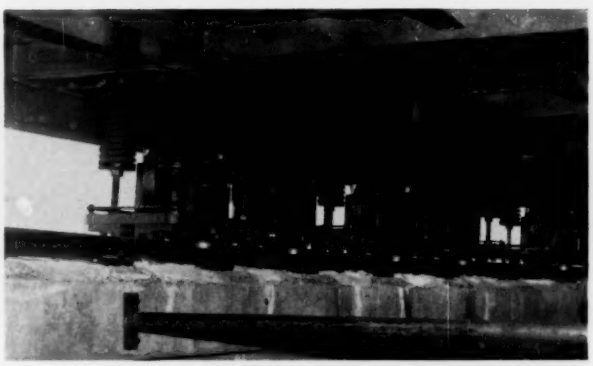
May 24, 1951. In this view toward the zenith of the dome, the slit opening extends to the left, with the 15-ton crane in the lower center. Above the arch girder is the first horizontal course of braces for the rib girders.



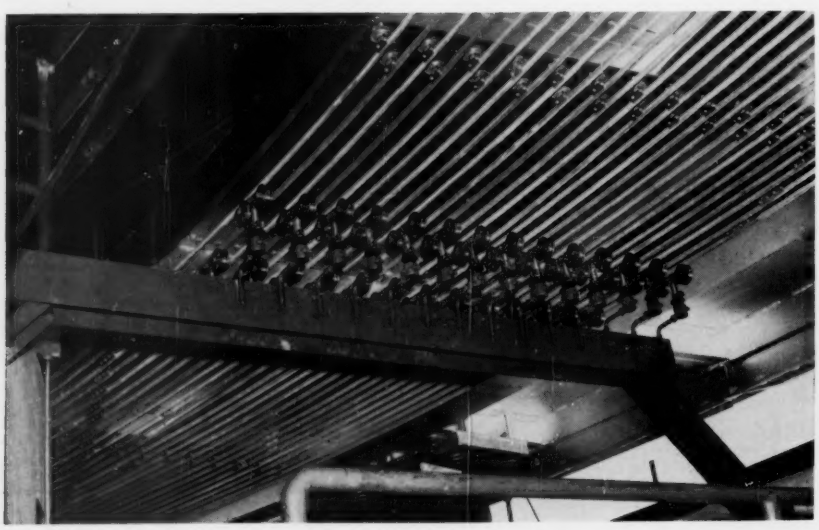
June 8, 1951. The plates that are being used to cover the skeleton of the dome are of $\frac{1}{4}$-inch steel preformed to the proper curvature. Each plate overlaps the other slightly, and they are welded together at the seams.



Left: June 8, 1951. W. W. Baustian holds two of the panels that line the dome interior. About three inches thick, each tray contains seven layers of aluminum foil, and the side that will be exposed inside the dome has an inch-square waffle pattern (as at Mr. Baustian's right). This surface gives a uniform appearance to the interior of the dome, and good acoustical properties.

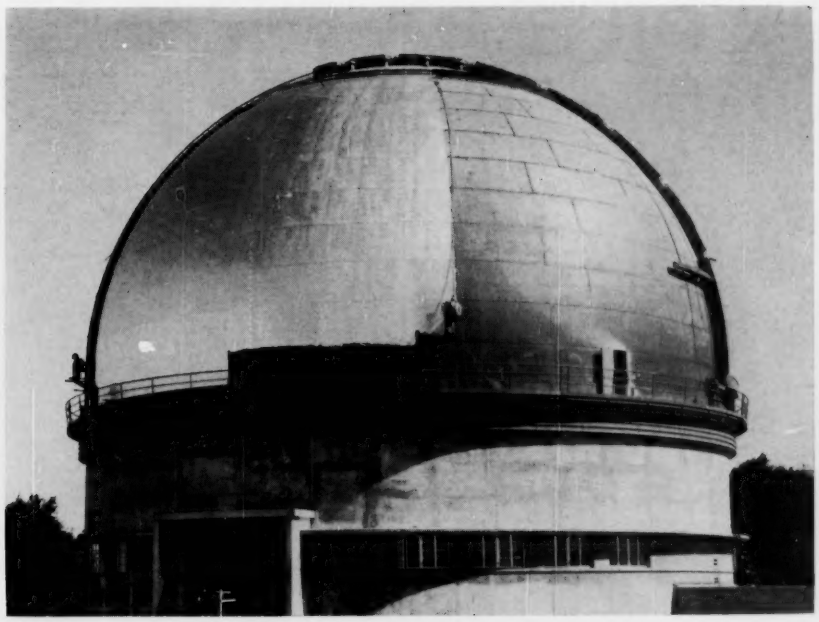


Above: June 12, 1951. The weight of the 260-ton dome is carried upon 30 trucks. Those shown here are under the slit section (as in the picture of April 10, 1951), to which the arch girders transmit the load of the crane—up to 30 tons maximum. Therefore these trucks, 12 in all, are heavier and closer together than the 18 rib trucks spaced around the remainder of the dome. This picture shows the lower side of the ring girder before the electrical trolley system was installed.



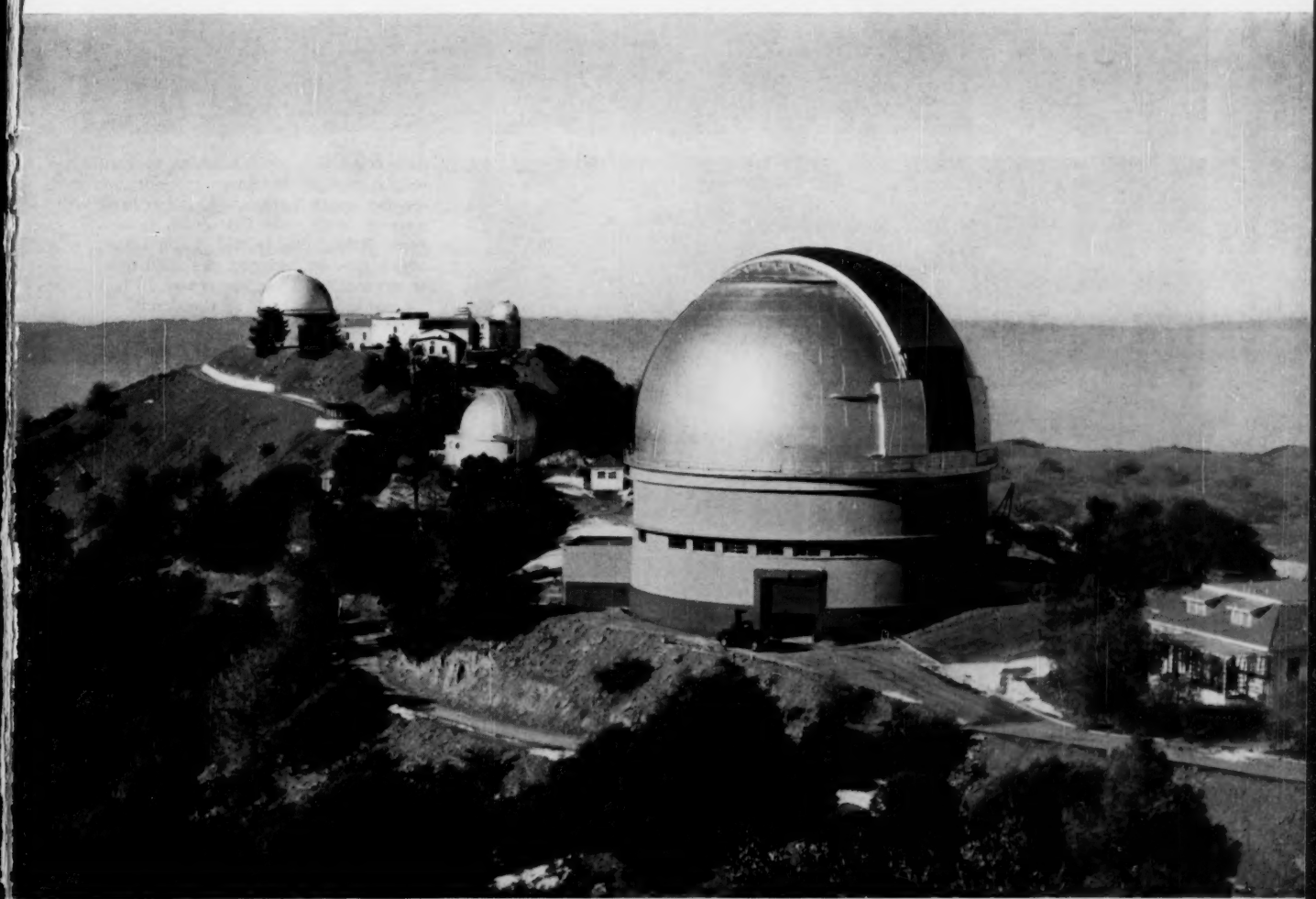
Left: June 27, 1951. This system of 27 trolleys and their conductor bars transmits power and miscellaneous control circuits between the moving dome and the stationary part of the building. The bars, averaging 300 feet in length, are attached to the under side of the ring girder, which is eight feet wide. The open space around the dome, that shows below the outside (right) edge of the ring girder, will be closed later.

June 29, 1951. A section of the main shutter is being hoisted into place. Six such parts, totaling five tons, make up the 72-foot upper shutter.

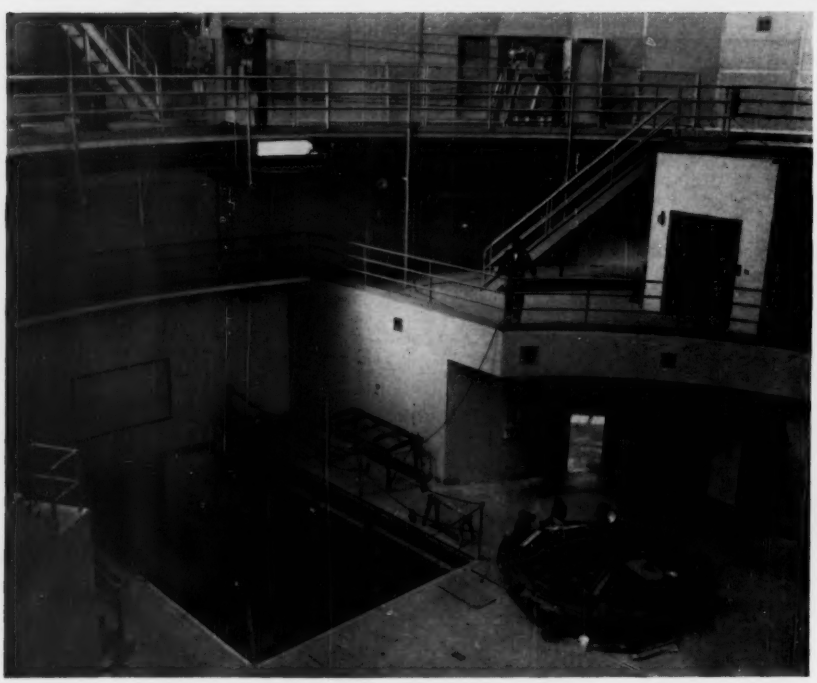


Above: October 18, 1951. The dome gets the first of its two coats of aluminum paint, over a red lead primer coat. The louvers that ventilate the dome can be seen, just above a rail from which hang the bosun's chairs for the painters. The space above the ring of louvers is vented by eight mushroom ventilators, four of which are visible here.

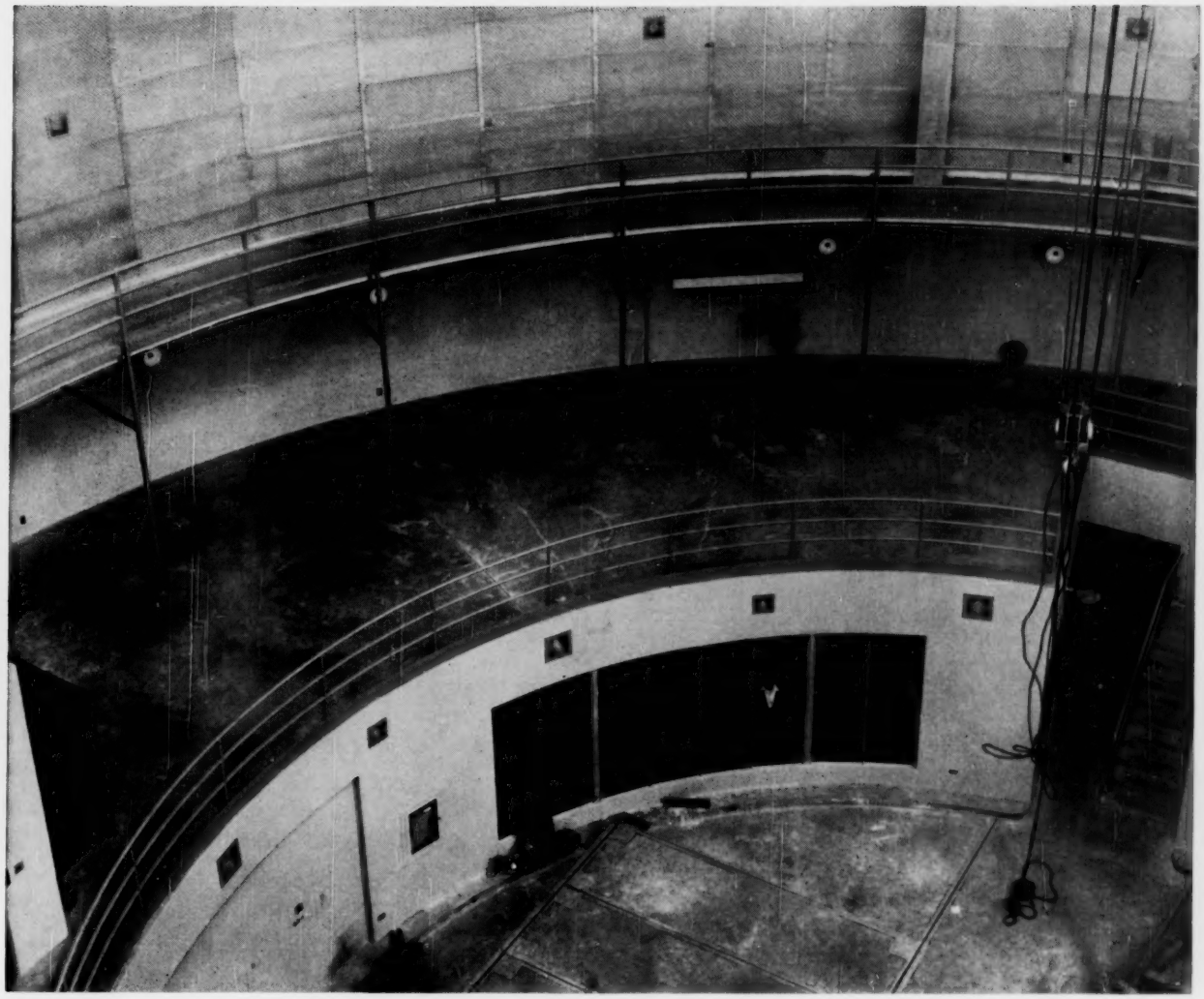
Below: January 28, 1952. The completed dome dominates the scene as photographed from the water tank on Kepler Peak. The overhead and bi-parting shutters are well shown. To the left is the housing of the 20-inch astrographic refractor, and on the summit beyond is the main observatory building, with domes for the 36-inch and 12-inch refractors.



Above: April 3, 1952. Looking upward to the top of the dome interior, we see the upper shutter, which has been opened until only the zenith is covered. Below this is the 15-ton crane, which may be rerigged to lift 30 tons. It has a travel from the center 16 feet toward the back of the dome.



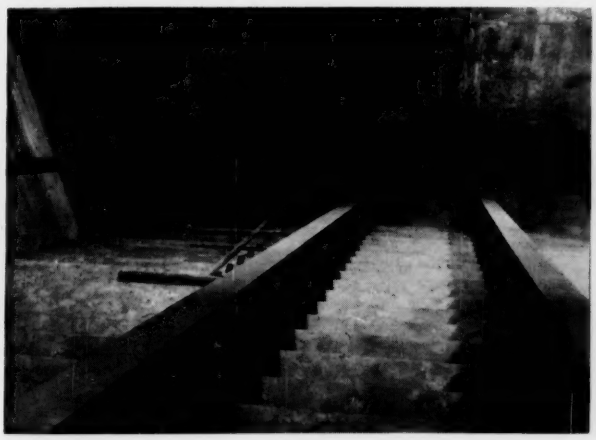
Left: April 3, 1952. This is the dome interior, looking southwest. The mounting base will fit into the cutout in the second floor at the lower left; within this, the dark opening in the wall leads to the coude room. Lying on the second floor is the 120-inch cast-iron mirror cell purchased from Caltech, and on top of this is a 100-inch tool. This cell was used to support the mirror during the rough-grinding operation before the telescope mirror cell was completed. The elevator at the right starts at the ground floor. The stairs in right center lead up to the ring girder, which also serves as the interior walkway around the dome.



These pictures were all taken on April 3, 1952, before installation of the instrument. Above, the view is northwesterly toward the glassed-in visitors' gallery on the second floor. The three covers of the hatch over the mirror-grinding pit may be seen in front of the gallery. One of the dome drive units is visible on the small shelf under the dome walk.

Lower left: Looking down into the coude room, which is located outside the main building at the south end of the telescope. The room is 24 feet wide and 25 feet long horizontally. Its floor at the south end is 13 feet below the level of the observatory ground floor. The girders are not part of the final equipment; they are being stored here. The steps will also serve as future footings for spectrographic apparatus.

Lower right: The combined library and lounge has a kitchen adjoining, glimpsed through the open door.



SOME PHOTOELECTRIC PROBLEMS

OTTO STRUVE, *Leuschner Observatory, University of California*

OBSERVATIONS of the magnitudes and colors of the faintest stars and galaxies detectable with giant telescopes are needed for the solution of some of astronomy's most far-reaching problems. Among these are the structure and mechanics of the universe, the ages and evolutionary histories of the stars.

Therefore, there is practical importance in some recent studies of the limiting magnitudes now attainable with the 200-inch telescope, and of the possibilities of reaching even fainter stars and galaxies, by both photographic and electronic techniques. To understand this photometric work, we must first consider what is meant by the statistician's term, "a Poisson distribution."

Many years ago a famous British statistician, who used the pseudonym "Student" in his writing, counted yeast cells under a microscope, to find how they were distributed over 400 squares, each 0.05 by 0.05 millimeter, ruled on a glass plate. All 400 squares fitted into an area of one square millimeter. The counts are plotted here: 20 squares contained one cell each, 43 contained two cells each, and so on. No squares contained more than 12 cells. The total number of cells counted was 1,872.

This curve of the frequency distribution of the yeast cells is typical of a Poisson distribution, of which there are many other examples in biology, as well as in astronomy. The numbers are not symmetrical about the maximum. These Poisson frequencies are unlike those of a Gaussian or "normal probability" distribution, with which the reader may be more familiar. Were the yeast counts represented by a normal probability curve, it would be symmetrical on both sides of a maximum at 4.68 cells, which is the arithmetic average of the counted cells per square.

Poisson distributions like this arise when the recorded numbers are discontinuous (the number of yeast cells cannot be a fraction), and when the probability of a particular cell falling in a particular square is independent of how many cells happen to be in any other square. If the number of yeast cells per square should be increased indefinitely, however, the Poisson distribution would resemble a Gaussian distribution more and more.

(1) Number of cells	(2) Frequency observed	(3) Frequency expected	(4) Difference	(5) (4)² × (2)
0	0	3.71	−4.68	0
1	20	17.37	−3.68	270.80
2	43	40.65	−2.68	308.74
3	53	63.41	−1.68	149.46
4	86	74.19	−0.68	39.56
5	70	69.44	0.32	7.00
6	54	54.16	1.32	93.96
7	37	36.21	2.32	199.06
8	18	21.18	3.32	198.36
9	10	11.02	4.32	186.60
10	5	5.16	5.32	141.50
11	2	2.19	6.32	79.88
12	2	0.86	7.32	107.16
13	0	0.31	8.32	0
14	0	0.10	9.32	0
15	0	0.03	10.32	0
16	0	0.01	11.32	0
Total	400	400.00		1782.08
Mean	4.68			4.46

The table gives the actual observed number of yeast cells in Student's experiment. The average number of cells per square is 4.68, and the formula for Poisson's distribution curve involves the factor $e^{-4.68} = 0.00928$ (where e is 2.718+, the base of natural logarithms). The formula then tells us that the expected numbers of squares containing, respectively, 0, 1, 2, 3, cells, and so on, are:

0 $400 \times 0.00928 = 3.71$

1 $4.68 \times 400 \times 0.00928 = 17.37$

2 $\frac{1}{2} \times 4.68^2 \times 400 \times 0.00928 = 40.65$

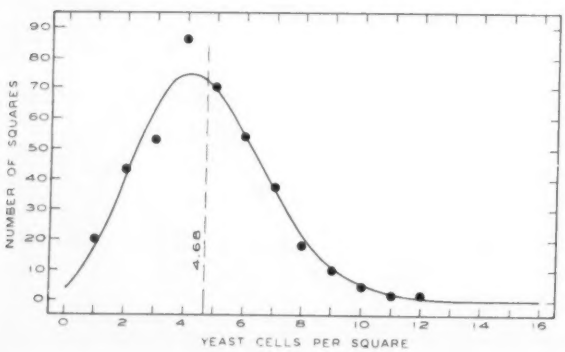
3 $\frac{1}{3} \times \frac{1}{2} \times 4.68^3 \times 400 \times 0.00928 = 63.41$

The next additional factor will be $\frac{1}{4}$, and the power of 4.68 will be 4, and so forth. The expected numbers are shown in column 3 of the table; they agree reasonably well with the observed frequencies. They are plotted as a curve in the diagram.

Columns 4 and 5 of the table allow us to find an important property of the distribution, its spread. This is mathematically expressed by its root mean square deviation, or mean error as the astronomers call it. In the fourth column is the difference: number of cells counted *minus* the average number per square (4.68). In the fifth column, this difference is squared and multiplied by the corresponding observed frequency (column 2). Summing the entries in the last column gives 1,782.08, and dividing this by 400 gives the mean square error as 4.46. We notice that this is almost equal to 4.68, the average number of yeast cells per square. The small disagreement means that the observed distribution is not *exactly* in accordance with Poisson's law. More precisely, we should compare the square roots of these numbers, the root mean square error, 2.11, and the square root of the arithmetic mean, 2.16.

Certain properties of frequency distributions of this type are important in astronomical applications. The total number of cells counted in Student's experiment was 1,872; but if he had made a new count, under exactly the same conditions, he would not have obtained 1,872, but some other number. Additional counts would give still other numbers, each comprising a distribution according to Poisson's law. These numbers would themselves then form a Poisson distribution, but because of the large number of cells in each total count the new distribution would rather closely resemble the symmetrical distribution of a Gaussian curve.

Let us assume that the average of such total counts would be about 1,872, the square root of which is 43.3, the root mean square error of this distribution. Since this is 2.3 per cent of 1,872, we



Counts of randomly distributed objects, like grains in a photographic emulsion, usually follow Poisson's law. Here a Poisson curve has been fitted to the dots representing Student's counts of yeast cells.

could conclude that the density of cells in the large area of one millimeter is estimated with this measure of precision. Note that this conclusion is reached without actually making the several independent counts mentioned above, but it requires that the number of items counted be large.

Let us apply these ideas to the problem of photoelectric photometry. Essentially, determining the brightness of a star photoelectrically amounts to counting the electrons liberated as light quanta hit the sensitive surface of the cathode. The light quanta from a star come at irregular intervals; they are distributed in a random manner with respect to time. Furthermore, not every quantum produces an electron when it strikes the cathode—this is again a random process. Therefore, the number of electrons ejected in successive one-second intervals will fluctuate, and individual counts made in different one-second intervals will be distributed according to Poisson's law.

We need not actually count numerous small intervals separately, but may find their average by determining, for example, how many electrons are liberated in one minute, and dividing this total by 60. This average number of electrons emitted in one second will have an uncertainty proportional to its square root.

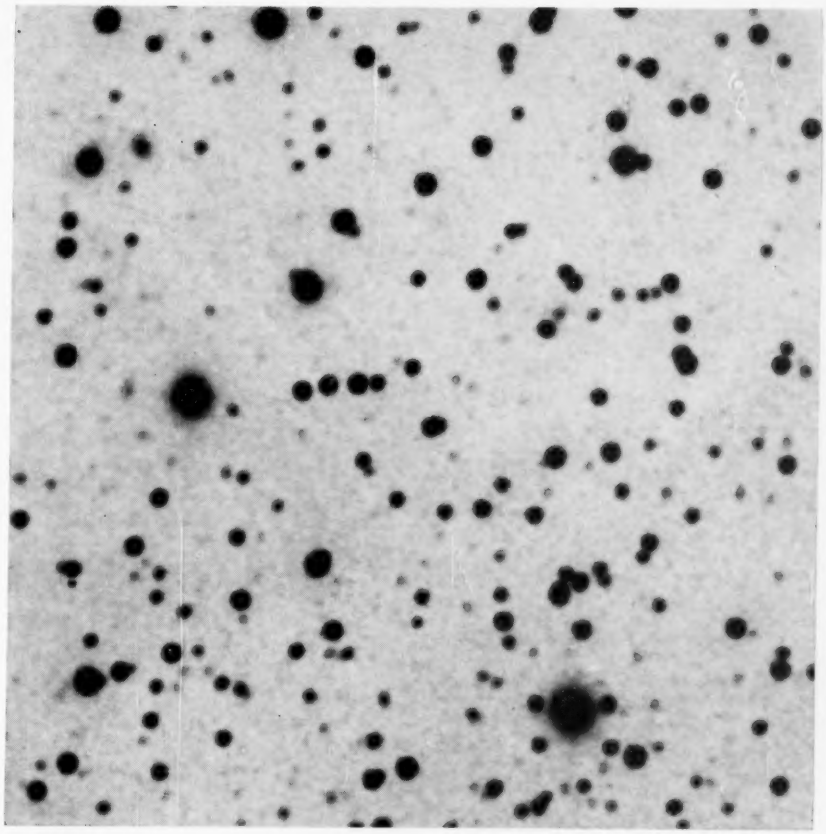
This is why photoelectric photometry of the faintest stars becomes uncertain and difficult, for the thinness of the rain of photons from the star means few electrons to count. Suppose the statistical uncertainty in electron count amounted to 15 per cent, for a very faint star. This would produce an uncertainty in measured light intensity of 15 per cent, or ±0.152 magnitude, and in practice we should allow for an uncertainty even greater than this.

To reduce this large uncertainty, we would have to lengthen the time during which we collect electrons, hence increasing their number and reducing the percentage uncertainty. The importance of this consideration may be seen from W. A. Baum's recent estimate that in order to attain for a 23rd-magnitude star an accuracy of 0.05 magnitude (in only one color), *one full night* of good seeing with the 200-inch Hale telescope would be required!

In stellar or nebular photometry we have two fundamental problems:

1. To reduce the time required to make a measurement. In photographic work this can be done with telescopes of larger aperture or with faster emulsions. With photoelectric devices, we would like to obtain a reliable value of the electron count in as short an interval as possible.

2. To enhance the contrast between the diffuse background luminosity of the night sky and the light of faint stars and nebulae. This requirement is especially important in reaching the faintest objects. The light of the night sky is always present, and it sets a limit to the faintness of a star observable either photographically or photoelectrically that cannot be overcome by building larger telescopes or by inventing more sensitive emulsions or photoelectric receivers.



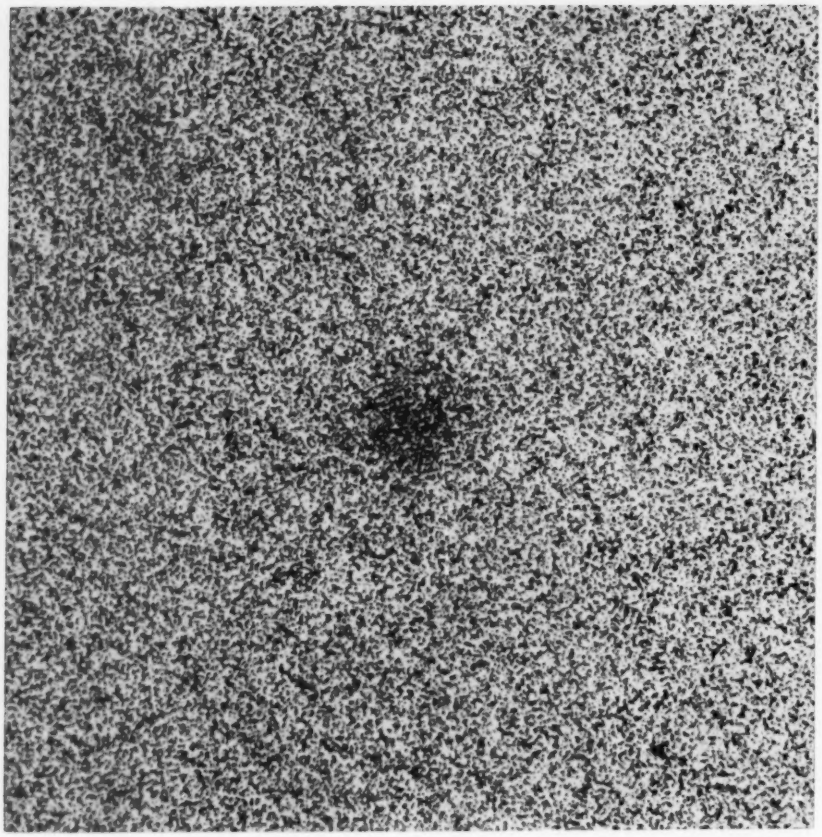
An enlargement of one square centimeter of a photograph taken with the 200-inch telescope, furnished by Dr. W. A. Baum to show that the images are fuzzy blobs rather than sharp points even in good seeing. The magnitudes in this picture range from about 12th to 23rd; among the faintest objects galaxies outnumber stars. Mount Wilson and Palomar Observatories photograph.

There have been marked advances during the past few years in the solution of both of these problems. In photoelectric technique the most spectacular progress has been made by A. Lallemand, of the Paris Observatory, especially in regard to the first problem. The second, in some respects the more fundamental of the two, was discussed by Dr. Baum at the meeting of the American Astronomical Society in June, 1954.

Dr. Baum starts by considering photographic methods. He has made a 12-times enlargement of a relatively short exposure of a field of stars and galaxies made on a night of good seeing with the 200-inch telescope. The accompanying reproduction shows the background sky as a light gray surface upon which the star images are superposed. Doubling the exposure brings out more stars, but it also increases the photographic density of the background sky. Experience with the Hale telescope has shown that after about 30 minutes on a fast, blue-sensitive emulsion (Eastman 103a-O) this background becomes so dark on the negative that no additional faint star images are brought out even if we increase the exposure time to one hour.

The star images are not geometrical points, but are enlarged by the spreading of light in the photographic emulsion. Turbulence of our atmosphere also produces some spreading, so that even on very quiet nights the smallest star images are about 0.1 millimeter in diameter. With the focal length of 666 inches at the prime focus of the 200-inch, this corresponds to about one second of arc.

It is true that the theoretical visual resolving power of the 200-inch telescope is given by the familiar Dawes formula as 4.56/200 second. Hence, visual observers could, during brief moments of excellent seeing, resolve double stars with separations of the order of 0.02 second,



This is an enlargement (about 122 times) of the image of a 20.5-magnitude star centered on one square millimeter of an Eastman 103a-O plate, exposed five minutes with the 200-inch Hale reflector. Mount Wilson and Palomar Observatories photograph.

but during a long exposure this resolving power is never achieved. Instead, as we have seen, the photographic resolution corresponds more nearly to one second, and even this is rare at Palomar, being recorded perhaps only 1/10 of the time the sky is clear.

The background illumination of the sky is not due to artificial lights. (The latter are serious at Mount Wilson, but they do not interfere with the work at Palomar.) The upper atmosphere of the earth might be called a faintly luminous gaseous nebula. The molecules and atoms are excited during the day by sunlight; their energy transformations during the night cause the emission of numerous monochromatic radiations, such as those of neutral oxygen (the green line of the aurora and the air glow), sodium, nitrogen molecules, and so forth. In addition, there is a feeble glow from all the faint stars and galaxies.

The resulting spectrum of the night sky is a combination of a continuum and a large number of emission lines. In principle, we should be able to filter out the emission lines, but in practice they are spaced so closely together that light filters can only get rid of a few of the most intense ones, such as the neutral oxygen radiation.

The air-glow emission lines are variable in intensity from season to season, and even in the course of a single night. They also differ with the latitude of the observatory. But these changes are relatively small, and even though we could gain a little by concentrating our work during the hours of minimum air-glow intensity, we cannot effectively get rid of it.

On an average moonless night, the air glow sheds about twice as much light upon the earth's surface as all the stars combined. This corresponds to spreading the light of a 4th-magnitude star uniformly over each square degree of the photographic plate.

As we have seen, for the 200-inch telescope each star image in good seeing covers an area of one square second of arc—about 1/100 of a square millimeter—which Baum calls a picture element. There are nearly 13 million such elements within a square degree, and the stellar magnitude of the air glow per picture element is thus 22.

Suppose now that we photograph a star whose magnitude is also 22. The picture element containing the star image receives twice as much light as from the night sky alone, and the negative reveals the star "as a tiny gray disk superposed on a light gray background." Such an image is easily detected on the negative.

But suppose that the star is of magnitude 23, only 2/5 as bright as a 22nd-magnitude star. It will add only 40 per cent to the background fog. A star of magnitude 24 would, similarly, add only 16 per cent.

How sure are we that we can see the slight darkening of a 24th-magnitude star on the negative? First we must ask what it is that we actually measure. The photographic emulsion is a thin, yellowish, translucent layer of silver halide grains suspended in gelatin. In a fast, blue-sensitive emulsion the individual grains, or clusters of grains, are each about five microns in diameter. (A micron is 1/1,000 millimeter.) These grains can be directly counted in each square (0.1 by 0.1 millimeter) picture area.

In a 30-minute exposure with the 200-inch telescope, each picture element of the night sky contains about 1,000 developed grains. The number of photons that strike the emulsion in this time is vastly greater, about 1,000,000. We infer that the "quantum efficiency" of the emulsion is only 0.1 per cent. This is due to three causes: first, only about 10 per cent of the incident photons are absorbed by the emulsion, the rest being diffusely scattered and reflected; second, it takes about 10 photons to make one developed grain; third, many photons are wasted because they do not combine in proper bunches of at least 10 to produce one grain.

Baum's enlargement of one square millimeter of a plate exposed only five minutes has a star of magnitude 20.5 near the center. If the exposure time had been 30 minutes, there would be more developed grains in the sky background—about 1,000 per picture element as mentioned above. We could actually count these grains in each of the 100 picture elements and compute the root mean square as was done for the yeast cells. But we could also infer directly that the root mean square of the individual counts per picture element must be very nearly the square root of 1,000, or 33. The uncertainty then becomes 33/1,000, or about three per cent.

We cannot expect, however, to distinguish a star with certainty from statistical irregularities of the background unless its contribution is several times larger than three per cent. Baum arbitrarily sets the limit of detectability at about 15 per cent, which requires 1,150 grains per picture element in the star image. As we have seen, a 24th-magnitude star adds 16

(Continued on page 192)

Amateur Astronomers

Well-known Eastern Amateur Astronomer Dies

SETTIN' ELMER'S GLASS (The Ridicule Method)

Listen, all ye telescopers, all ye sweepers and sky gropers,
To the tale I have to tell:
'Twas down on old Long Island, at Elmer's on Bay View,
That we started in to set his glass, we were an able crew:
There was Campbell with his ridicule fresh from the H.C.O.,
And Baron Yalden with his beard, the one he needs to mow;
The Secretary joined the gang to keep the parties happy,
For when the experts set a glass they are a wee bit scrappy.

William Tyler Olcott
AAVSO *Variable Comments*, Vol. 1, No. 1, 1924

Charles W. Elmer (1872-1954).

DECEMBER 7, 1954, marked the passing of the last of the famous group mentioned in the above stanza. Charles W. Elmer was one of the men most closely connected with the development of a place in American astronomy for the amateur astronomer. He was very active in the early years of the American Association of Variable Star Observers, and with his wonderful sense of humor contributed a great deal to the good fellowship of the association.

Mr. Elmer was a partner in a well-known firm of court reporters in New York City, but his greatest interest lay in astronomy and particularly in telescopic equipment. His home in Southold, Long Island, was literally surrounded by telescopes of all kinds and sizes, with concrete piers for portables and revolving domes for larger refractors and reflectors scattered through his flower beds. A 5-inch polar telescope, patterned after the 12-inch used for many years at Harvard Observatory by Leon Campbell, extended from an upstairs window.

It was well known, among all his friends, that Charlie Elmer's astronomical life consisted of 99 per cent enthusiasm and one per cent experience. Great excitement reigned at a meeting of the AAVSO in 1924 when a telegram arrived from Mr. Elmer reporting one observation made with his polar telescope. His good fairy was watching over him, for that observation found SS Cygni at maximum light. His total number of variable star observations could be counted on two hands, but he made up for that lack in other ways.

He gave the AAVSO a number of small refractors for loan to observers, and a splendid 6-inch refractor to be sent to India, where it is still doing noble work in the hands of R. G. Chandra.

A real patron of astronomy, Mr. Elmer made generous gifts to Harvard Observatory, helped in the founding in the late 1920's of the Amateur Astronomers Association in New York, was director of the department of astronomy of the Brooklyn Academy of Sciences, served terms as president and secretary of the AAVSO, and was the founder of the Custer Institute on Long Island. Many gifts to the AAVSO from "Mr. Anonymous" were postmarked from Long Island.

In 1936, he and Richard S. Perkin formed the Perkin-Elmer Corporation, primarily to make instruments useful to astronomers. They soon expanded to other fields, and when the war broke out were making roof prisms, an Air Force panoramic camera, and many other military instruments. But Elmer's greatest love was the Armagh-Dunsink-Harvard 33-inch Baker-Schmidt telescope, installed at Harvard's Boyden station in South Africa in 1950.

The seventh merit award of the AAVSO was given to him in 1943, with the citation: "To Charles W. Elmer, who by his long continued service and devotion to the activities of the Association, has greatly furthered the work on the problem of stellar variation." His jolly laugh and jaunty air will always live in the memories of those who knew him.

MARGARET W. MAYALL, Recorder
American Association of
Variable Star Observers

THIS MONTH'S MEETINGS

Cambridge, Mass.: Bond Astronomical Club, 8 p.m., Harvard Observatory. March 3, Dr. Bart J. Bok, Harvard Observatory, "Gas, Dust and Stars."

Chicago, Ill.: Burnham Astronomical Society, 3 p.m., Adler Planetarium. March 13, Dr. G. C. McVittie, University of Illinois, "Why Should an Astronomer Study Relativity?"

Cleveland, Ohio: Cleveland Astronomical Society, 8 p.m., Warner and Swasey Observatory. March 11, Dr. John D. Kraus, Ohio State University, "New Discoveries in Radio Astronomy."

Dallas, Tex.: Texas Astronomical Society, 8 p.m., Lone Star Gas Co. auditorium. March 28, film, "Remote Parts of the Universe."

Ft. Worth, Tex.: Ft. Worth Astronomical Society, 7:30 p.m., Children's Museum. March 24, Dr. F. K. Edmondson, Indiana University, "Exploring the Milky Way."

Geneva, Ill.: Fox Valley Astronomical Society, 8 p.m., City Hall. March 9, symposium: Prof. Clarence R. Smith, "Our Day Star"; Frank Hancock, "The Universe of Suns."

Long Beach, Calif.: Excelsior Telescope Club, 8 p.m., home of T. R. Cave, Jr., 265 Roswell Ave. March 25, T. R. Cave, Jr., "Jupiter."

Minneapolis, Minn.: Minneapolis Astronomy Club, 7:30 p.m., Science Museum. March 2, Wensell S. Frantzich, "The Sun."

Montreal, P. Q.: Royal Astronomical Society of Canada, 8:15 p.m., McGill University. March 7, E. E. Bridgen, "Saturn."

New York, N. Y.: Amateur Astronomers Association, 8 p.m., American Museum of Natural History. March 2, Dr. Uco van Wijk, Princeton University Observatory, "Inconstant Stars: The Study of Variables."

Rutherford, N. J.: Rutherford Astronomical Society, 8:15 p.m., YMCA. March 3, John Grinch, "Velikovsky's Worlds in Collision." James Pastorfield, "The Equinoxes."

St. Louis, Mo.: St. Louis Amateur Astronomical Society, 8 p.m., St. Louis Institute of Technology. March 18, Stuart O'Byrne, "Amateur Society Observatories."

South Bend, Ind.: St. Joseph Valley Astronomers, 7:30 p.m., YMCA. March 3, Fred Urednick, "Rockets."

Washington, D. C.: National Capital Astronomers, 8:15 p.m., Commerce Department auditorium. March 5, panel of experts, moderator, Charles A. Federer, Jr., Harvard Observatory.

☆ ☆ SKY AND TEACHER ☆ ☆

Sponsored by the
Teachers' Committee of the American Astronomical Society

SUPPORT FOR RESEARCH

RESEARCH CORPORATION was first impressed in 1941 with the fact that astronomy is a physical science. The foundation had been in existence since 1912, and its interests had been primarily in the support of fundamental research in physics, chemistry, mathematics, and the like. The meritorious demands of these fields were such that there had been no occasion for the Research Corporation to search out other areas in need of support.

Donald H. Menzel's request in 1941 for modest funds to help construct a coronagraph was, apparently, the point of discovery of astronomy's and Research Corporation's mutuality of interests. Starting with the grant in accordance with Dr. Menzel's proposal, Research Corporation has in the past 13 years developed a very real and continuing interest in this field. There are presently active some 13 Research Corporation grants in astronomy, representing about $85,000 in more-or-less current funds. This non-precise phraseology is used because Research Corporation grants are not tied to specific calendar or fiscal years.

At the end of World War II, we directed our interests primarily toward the needs of the smaller institutions of liberal arts and sciences and to the needs of the younger science teachers who wished to initiate or maintain some research activity. Since the announcement of the program, some 2,000 formal applications have resulted in the support of about 1,200 projects at nearly 400 institutions, and some 75 per cent of the projects have had renewed support one or more times. Of the approximately 300 new and renewal grants in the physical sciences made annually during this period, there has been an average of about 10 in astronomy, less than half of which, under any reasonable definition, were to "smaller" institutions.

We take as much pride and interest in work Research Corporation has helped support at, for example, Whittier College, Lewis and Clark, Agnes Scott, Wesleyan, Colgate, and Swarthmore, as in work for which grants have been made at the major centers and larger universities, such as Yerkes, McMath-Hulbert, and the University of California. However, we could wish for a heavier distribution among astronomy teachers in the smaller institutions. Possibly teaching loads and routine duties in most of the liberal arts colleges afford no time for many teachers of astronomy to consider research; possibly the kind of support available from Research Corporation does not meet the needs of research-minded astronomers in many of the smaller institutions.

Research Corporation grants are made to academic (sometimes other) nonprofit institutions. They are made on the basis of application by a regular staff member of the institution, usually for support of some reasonably specific program of research, and they require the interest of the institution itself at least to the extent of endorsement of the application. The grants are intended to cover the unusual, out-of-pocket costs of the project, not to underwrite its total costs of time, facilities, and the like. Thus, funds are available for special equipment and supplies, and for assistance in the form of fellowships or wages for part-time skilled labor. They are not available for procurement of routine supplies or facilities which would normally be expected to be available at an institution of higher learning, nor are they intended to provide for any parts of the salaries of regular staff members or other expenses which constitute normal institutional costs of operation, including overhead.

The requirement of a reasonably specific project or program, which can be summarized on Research Corporation's brief application forms, enables our advisory committee on grants to form some judgment of the values, educational and/or scientific, which may be realized from the expenditure of the funds requested. It is not intended to limit grants to the procurement of apparatus or equipment useful only for the specified project; on the contrary, it is a distinct plus factor in consideration of a proposal if permanent or semipermanent additions to instrumentation are contemplated which will be of continuing use in the institution's educational and research activities over an extended period of time.

Recently, we have begun a project completely novel to Research Corporation. We are in the process of acquiring several Questar telescopes which we propose to make available on loan to science and astronomy teachers who may be able to set forth interesting uses to which they might put such a device. This experiment is being tried on our conviction that this instrument is unique as a teaching aid and that exposure of some young minds to its optical, mechanical, and observing features will stimulate them to a real interest in science generally and in astronomy in particular.

Our field representatives travel extensively, visiting colleges and universities, and will welcome inquiries and opportunities to discuss or correspond with individuals who would like more information. William A. Woods, whose office is at 225 Santa Monica Blvd., Santa Monica, Calif., represents Research Corporation in the 11 western states. East of those to the Mississippi and Ohio Rivers, Walter E. Thwaite, Jr., with offices at Room 1316, 228 North LaSalle St., Chicago 1, Ill., is the representative. Alfred Kelleher, at the main office, 405 Lexington Ave., New York 17, N. Y., is field representative in the East.

CHARLES H. SCHAUER
Director, Division of Grants
Research Corporation

BOOKS FOR AMATEURS—concluded

TELESCOPE MAKING

Amateur Telescope Making, Albert G. Ingalls, editor. Scientific American, Inc., New York. Vol. 1, 1933, $5.00; Vol. 2 (Advanced), 1937, $6.00; Vol. 3, 1953, $7.00. This famous series has grown with the years. The first volume tells how to make a reflecting telescope, but does not pin the amateur down to hard and fast specifications. The second volume discusses advanced mirror-making techniques, flat making, eyepiece work, telescope drives, aluminizing, and other topics for the experienced telescope maker. In the third volume are 44 chapters by men of outstanding optical experience. Among the great variety of subjects covered are a system for astronomical photography, the construction of a Maksutov correcting lens, an inexpensive photoelectric photometer, Schmidt cameras, and how to make a flat that is really flat.

Making Your Own Telescope, Allyn J. Thompson. Sky Publishing Corporation, Cambridge, Mass., 1947, $4.00. A book for the beginner containing in systematic fashion all the practical instruction he will need to construct and mount a 6-inch reflecting telescope.

OPTICAL SOCIETY MEETING

The spring meeting of the Optical Society of America will be held at the Hotel Statler, New York City, on April 7, 8, and 9. The program will feature a symposium on optical molecular spectroscopy, including the following papers:

"Recent Work on the Spectra of Simple Polyatomic Molecules," G. Herzberg, National Research Council of Canada.

"Resonance Interactions and the Infrared Spectra of Polyatomic Molecules," H. H. Nielsen, Ohio State University.

At the society dinner on Friday evening, April 8th, Ralph M. Evans, Eastman Kodak Company, will talk on "Color and Brightness in Projected Color Pictures."

Optical Society meetings are open to nonmembers. Copies of the program will be published four weeks in advance and may be obtained from Dr. Arthur C. Hardy, Massachusetts Institute of Technology, Cambridge 39, Mass.

NEWS NOTES

By Dorrit Hoffleit

ATMOSPHERIC LUNAR TIDES

The atmosphere of the earth, like its oceans, is subject to tidal effects caused by the gravitational pulls of the sun and the moon. While less obvious than ocean tides, those in the atmosphere have been recognized in long series of barometric pressure records. The lunar tides are discussed by Ryukichi Sawada in the *Meteorological Papers* of New York University, where he presents computations based on theories developed earlier by S. S. Hough and by C. L. Pekeris and M. V. Wilkes, and on upper atmospheric temperatures obtained chiefly from high-altitude rockets.

One of Sawada's results is that maximum surface pressure occurs 30 minutes after the moon crosses the local meridian when the ozonosphere has a temperature of 325° absolute; if the temperature is 307°, however, the maximum occurs two hours after the lunar transit. The temperature of the ionosphere modifies both amplitude and time of the maximum lunar tide slightly but not negligibly.

Peculiar seasonal variations of the pressure oscillation caused by atmospheric tides, already found by Chapman, are interpreted by Sawada to be caused by seasonal variations in the mean temperatures of the ionosphere and the ozonosphere.

EXPANDING UNIVERSE DATA

At the Berkeley meeting of Section D of the American Association for the Advancement of Science, in December, Dr. Allan Sandage described further work by Mount Wilson and Palomar astronomers on the red shifts and distances of galaxies. He extended the information reported in our April, 1954, issue, pages 188 and 189.

Dr. Edison Pettit has completed photoelectric measures of the apparent magnitudes of most of the nearly 800 galaxies for which radial velocities have been observed. From these magnitudes the individual distances may be estimated. The range of distance now covered is 60 times greater than that available to Hubble when he first enunciated the red-shift-distance relation from 24 galaxies in 1929.

Dr. Sandage has made a preliminary analysis of this massive material, whose complete study will take about four years. In 1936, Hubble found that the red shift increases with distance at a constant rate of 530 kilometers per second per million parsecs. Dr. Sandage drastically revises this figure to about 180 kilometers per second. We can now say with some assurance that the relation is the same for all directions in space, and that it holds from the nearest to the farthest known distances.

Most of the change in the Hubble constant comes from recent revisions of the distance scale. The twofold increase in the distance of the Andromeda galaxy should not be expected to hold for all other systems. The Virgo cluster is now placed 22 million light-years away, nearly three times its former estimated distance. The M81 group in Ursa Major is believed to be four times as far away as before. Several lines of evidence suggest an average correction factor of at least three to the 1936 distances.

It is still possible that the red shifts may result from some unknown property of light, but the age of the universe calculated from expanding universe theory may favor the latter interpretation of the red shifts. The expansion appears to have begun about four billion years ago, which is in reasonable agreement with independent estimates of the ages of the oldest stars and with geologists' determinations of the age of the earth.

ASTRONOMERS TO MEET AT PRINCETON

The American Astronomical Society will meet at Princeton University Observatory, Princeton, N. J., on April 3-6. The program will include a symposium on "Interrelations between Gas, Dust, and Stars." Dr. B. Stroemgren, director of Yerkes Observatory, will be chairman, and papers will be given by W. Baade, L. Biermann, and B. J. Bok.

The seventh Henry Norris Russell lecture will be given on Monday evening, April 4th, by Dr. Paul Merrill, of Mount Wilson and Palomar Observatories. On Tuesday afternoon, April 5th, the address of the retiring president will be by Dr. Robert R. McMath, of the McMath-Hulbert Observatory. The society dinner will be held that evening.

ANOTHER METEORITE FIND

Last month we noted the list of meteorite falls throughout the world compiled by Dr. F. C. Leonard, of the University of California. Now another fall may be added to the list, as the result of a recent chance meeting between Dr. Leonard and a visitor at the rim of Meteor Crater in Arizona. Sergeant L. M. Mauersberger, of Parks Air Force Base, Calif., showed the meteoriticist a stone weighing about three quarters of a pound that he had picked up on his farm near Marlow, Okla., in 1936.

The stone was identified by Dr. Leonard as a meteorite, consisting mainly of two characteristic minerals, olivine and enstatite. It had apparently been found only a short time after its fall, for an appreciable amount of fusion crust is still present on the predominantly oxidized surface. The stone was acquired for Dr. Leonard's collection at the University of California in Los Angeles.

TWO GOLD MEDAL AWARDS

Dirk Brouwer, director of Yale University Observatory, and Walter Baade, Mount Wilson and Palomar Observatories, will each be honored with a gold medal in 1955.

Dr. Brouwer is to receive the gold medal of the Royal Astronomical Society in London, and will deliver the society's George Darwin lecture. His many contributions to astronomy concern the methods of celestial mechanics, planetary and satellite motions, asteroids, variations in the period of the earth's rotation, and fundamental astronomical constants.

The Catherine Wolfe Bruce medal of the Astronomical Society of the Pacific will be given to Dr. Baade for his pioneering investigations on the structures of galaxies. It was his recognition of the existence of two different population types among the stars in the Andromeda nebula and also in our own galaxy that led to the recent important revision of the distance scale for galaxies.

NEUTRAL HYDROGEN AND ELLIPTICAL GALAXIES

An apparent departure from the mass-luminosity relation for some elliptical galaxies and members of the Coma cluster of galaxies, noted by M. Schwarzschild, may be resolved by the proposals of two graduate students at the Leuschner Observatory, Robert P. Kraft and Sidney M. Stone. They described their work at the December meeting of Section D, American Association for the Advancement of Science, at Berkeley, Calif.

Mr. Kraft suggested that most of the

IN THE CURRENT JOURNALS

THE FOUNDING OF THE MOUNT WILSON OBSERVATORY, by Walter S. Adams, *Publications*, Astronomical Society of the Pacific, December, 1954. "On December 20 [1904, Hale] started up Mount Wilson, riding a mule. . . . At Martin's Camp, a small mountain resort about a mile below the summit, he was called to the telephone. . . . The Executive Committee . . . had appropriated $150,000 a year for two years, and had given assurance of generous support in the future for additional construction and maintenance. . . . It is peculiarly fitting that Hale should have received this news on his way up Mount Wilson, and on the trail where he had done so much of his thinking and planning for the future."

mass in the elliptical systems may be neutral hydrogen gas, instead of stars. He called attention to the large hydrogen content of the Magellanic Clouds, found by Australian radio astronomy observations (see *Sky and Telescope,* December, 1954, page 56). Previously, astronomers had thought that systems of this type, composed predominantly of stars of Population II, would be essentially free of neutral interstellar hydrogen gas.

The Coma cluster, at a distance of about 80 million light-years, contains some 1,000 galaxies concentrated within a four-degree region of the sky. Mr. Stone suggested that if neutral hydrogen gas is present in this cluster it should be distributed in intergalactic clouds, since gas originally present in the individual galaxies would be swept out by collisions between them, as shown by L. Spitzer and W. Baade.

Since the intergalactic gas clouds might generally be at temperatures near absolute zero, no visible light would be radiated, but radio emission of 21 centimeters wave length should be quite strong, even possibly exceeding that from the relatively nearby Small Magellanic Cloud.

In order to detect the Coma cluster radiation, radio telescopes will probably have to be tuned to 21.6 instead of 21.1 centimeters, since the optically observed red shift for such distant galaxies amounts to about one part in 40, corresponding to a velocity of recession of almost 7,000 kilometers per second. If the neutral hydrogen radiation shows the corresponding Doppler shift, it will provide a strong confirmation of the optical observations on which the concept of the expanding universe is based.

ASTEROID PHOTOMETRY

Systematic photoelectric observations of asteroids have been carried out at McDonald Observatory since 1949 by Dr. G. P. Kuiper and his collaborators (see *Sky and Telescope,* March, 1953, page 129). Four recent papers in the *Astrophysical Journal* give their detailed results for 18 minor planets.

Seventeen of these show light variations such as would result from an irregularly shaped body in rapid rotation. The largest amplitude, 0.49 magnitude, was measured for 15 Eunomia. The periods run from a doubtful 18 hours for 10 Hygiea to four hours nine minutes for 22 Kalliope. The latter value is only 25 per cent longer than the shortest possible rotation period for an incompressible homogeneous fluid mass of density 3.5. It was also found that the rotation of 15 Eunomia is retrograde.

Color indexes for the asteroids have been determined with an accuracy of better than ±0.01 magnitude. The asteroids by no means have identical colors, but on the average they are comparable with the color of a *K*0 main-sequence star, except that they are stronger in ultraviolet light. In the latter respect, the asteroids are intermediate between Jupiter's moons, which have no ultraviolet excess, and bodies like Pluto and Triton (Neptune's satellite) with a marked excess. The colors of individual asteroids bear no relation to their relative sizes.

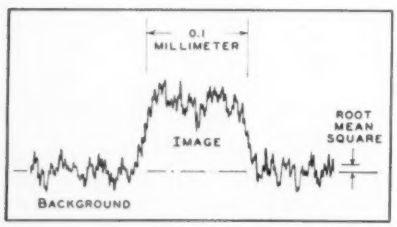
SOME PHOTOELECTRIC PROBLEMS

(Continued from page 188)

per cent to the background of the night sky, and this corresponds closely to Baum's limit.

The Palomar Observatory astronomer has observationally confirmed this calculation. He chose a star of 23.8 blue magnitude and 22.9 yellow magnitude, these values determined photoelectrically. A fully exposed yellow plate shows the star conspicuously. On a fully exposed blue plate, the star appears as a barely perceptible increase in the density of the background if one knows in advance where to look.

The similarity of Baum's treatment of photographic limiting magnitudes and the photon-counting method is shown by the microphotometer tracing of a section of the five-minute photograph on page 188. The individual wiggles of the tracing correspond to the departures from the mean of the individual grain counts per unit area or unit time. The root mean square is indicated on the right side. It is evident that to be sure of a star the general increase in the level of the curve must be several times larger than the root mean square.



A microphotometer scan of the image of a faint star on a 200-inch telescope negative, from Mount Wilson and Palomar Observatories.

But in order to make a fainter star detectable it is necessary to have more grains per picture element. This cannot be done by increasing the exposure beyond 30 minutes, for then the grains begin to coalesce and the background is overexposed. But an emulsion containing smaller grains should produce more grains per picture element without crowding them. Thus, a fine-grained emulsion should give better contrast. Up to a certain point this procedure is sound, but in practice it is limited by the prohibitive slowness of all fine-grained emulsions. Nevertheless, in the related problem of detecting a faint absorption line on the background of a continuous spectrum, fine-grained emulsions (such as Eastman Process) have yielded spectacular advances.

Can any photographic procedure reduce the uniform sky background? Baum concludes that no such procedure is in sight. Photography by itself does not appear to offer material improvement beyond the present limit of a blue magnitude of 24 attainable with the 200-inch telescope. But some novel electronic techniques, such as that of Lallemand mentioned above, are promising, and these will be described next month.

AUTHOR'S NOTE: Professor J. Neyman, director of the Statistical Laboratory of the University of California, has told me that Student's papers first appeared about 1904 in the periodical *Biometrika* and immediately aroused the keenest interest among statisticians. For nearly 20 years his identity remained a secret, and there were even rumors that the pseudonym was used by the Prince of Wales, the patron of the British Statistical Association.

In 1924, Mr. Neyman arrived in London as a postgraduate student. His first visit was to the office of the famous Karl Pearson, but the latter was away, and a friendly looking, bearded gentleman showed the visitor around. Asked if he happened to know the identity of Student, Mr. Neyman's host replied, "I know him well indeed. I am Student."

His name was W. S. Gosset, an Oxford graduate in chemistry and mathematics who in the early 1900's took a position as junior brewer at the Guinness Brewery in Dublin. Although his duties did not then involve statistics, he continued to work in that field. Having aroused the interest of a director of the company, who realized that statistical methods might be useful in the business, Gosset was sent to London to work under Pearson for several years. He was permitted to publish his scientific findings, but only under a pseudonym, presumably to prevent competitors from realizing that Guinness was using the services of a statistician.

Gosset remained on the brewery staff for the rest of his life, but the mystery of his name gradually became dispelled. In his later years he trained a number of younger members of the brewery in the methods of statistics, and all of them used pseudonyms in their publications. No doubt the yeast cells discussed in this article had some connection with Guinness' desire for anonymity.

BOOKS AND THE SKY

ASTROPHYSICS

Nuclear Transformations, Stellar Interiors, and Nebulae

Lawrence H. Aller. Ronald Press Co., New York, 1954. 291 pages. $12.00.

THIS is actually the second volume of Aller's *Astrophysics,* and prospective purchasers would have a clearer realization of the relationship between the two books if each had been assigned a volume number. In the previous volume, subtitled *The Atmospheres of the Sun and Stars,* the basic equations of atomic theory and of the physics of normal stellar atmospheres were given, and in the present work Dr. Aller avoids much repetition by referring the reader to the earlier volume for these derivations.

The first part of the present volume also deals with fundamental physics: nuclear reactions and the equations governing mechanical equilibrium and energy transfer under the conditions of high temperature and pressure holding within a star. A particularly valuable table, contributed by W. A. Fowler, summarizes the energy yields and cross-sections of the reactions which probably account for the bulk of the energy production in normal stars.

After an excellent discussion of the application of the general physical results to the construction of theoretical models of stars, there is a section on the origin of the chemical elements. This topic is sensibly kept brief, for the subject is just undergoing transformation from the stage of rather free speculation to that of quantitative application of reliable nuclear data. Since, however, a good summary is given of the theory of Alpher, Bethe and Gamow (the "$\alpha\beta\gamma$ theory") of the formation of elements from a primordial neutron gas during the early stages of the expansion of the universe, I feel that a better-balanced idea of current views would result if comparable space were given to the possibilities of element formation in very hot stars. Considerations of the latter type, initiated chiefly by Hoyle, offer some promise of explaining the observed abundances of heavy elements in important groups of stars, such as those of types *C* and *S*. This possibility is mentioned by Aller, but not discussed further.

The following chapter on Cepheids and long-period variables develops the relations between internal structure and the observable surface phenomena of a pulsating star. In introducing the subject, Aller reminds the reader that ". . . a study of pulsating stars may give information on stellar interiors that could not be found from objects in static equilibrium . . . By studies of the strange and exotic we throw new light on the unsolved problems of the atmospheres and interiors of giant and supergiant stars."

The second half of the volume deals with matter at low densities, passing from the extended envelopes surrounding certain giant stars and the expanding shells around novae, to planetary nebulae, and finally to the yet more tenuous gases and dust clouds of interstellar space. This progression from the most highly compressed gases inside stars, with densities of perhaps 100,000 grams per cubic centimeter in the degenerate cores of white dwarfs, to the low interstellar densities of the order of 10^{-24}, is probably the most logical way of presenting the immensely varied phenomena, but brings with it some disadvantages. Thus, the Zanstra method of estimating the temperature of a star—by photometry of the spectrum which it excites in a nearby gas cloud—was originally developed for the case of a planetary nebula, and the derivation of the equations is naturally given by Aller in Chapter 5, on planetary nebulae. At three earlier points in Chapter 4, however, he had already found it necessary to quote applications of the method to novae and variable stars. This is not a serious criticism of the arrangement of topics though, for it is doubtful that any different ordering would avoid all such forward references.

Even from this incomplete summary it is evident that the volume is largely concerned with those exciting problems which lie close to the borders of present astronomical knowledge. Consequently,

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it can be predicted that revised editions will be called for more quickly than in the case of works dealing with more fossilized subjects. This situation, together with the cost, which is high for such a relatively small book, creates a serious problem for students (and many others) who are likely to find that they cannot afford the book and yet cannot afford not to have it. The excellent quality of the photographic illustrations adds greatly to the value of the book; nevertheless it must be regretted that the publishers could not have found a less expensive format. Perhaps the solution to this common dilemma is to issue separate, cheaper "student editions" of such fundamental treatises.

Another consequence of the newness of much of the material is that the presentation sometimes oscillates between that of a textbook, stressing basic methods, and that of a research review which attempts to mention all the recent contributions to a subject. Some teachers who are already using the volume as a text have found it necessary to fill out the derivations in many sections with reading of the original papers. Fortunately, the bibliography at the end of each chapter is extensive and accompanied by helpful comments on each reference.

It is always easy to find individual points to criticize in such a comprehensive work, but, taken as a whole, Aller's *Astrophysics* succeeds brilliantly not only in telling the reader what has been done but also in giving him a feeling for the relative importance and difficulty of many of the unsolved problems which are engaging the most serious efforts of astronomers.

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SIR ISAAC NEWTON

E. N. da C. Andrade. The Macmillan Co., New York, 1954. 140 pages. $1.75.

TWO MAIN impressions are gained by the reader of this book—Professor Andrade's profound knowledge of his subject, though here condensed into a slim volume, and the vividness of his explanations. The series of which it forms a part is entitled "Brief Lives," and the publishers explain that they asked the author to prepare his text with younger readers in mind. The result is that he deals with problems of optics, the laws of gravitation and motion, even the meaning of the calculus, in such a clear style and with such a simplicity of language that few readers will have any difficulty in understanding what is meant.

The book is essentially an account of Newton's life, with the divisions of the text corresponding to well-marked periods of that life. As a background, the author gives a masterly description of the state of science at the time. The official teaching in the universities was still an exposition of the views of the Greek natural philosophers, with Aristotle as the supreme authority. These philosophers were more interested in speculating about the causes of phenomena than in discovering the laws according to which nature behaves, and they argued by deduction from accepted philosophical ideas, many of which were quite erroneous.

By 1650, however, the Renaissance of science was providing a new way of looking at its problems, initiated by men like Galileo, William Gilbert, and Kepler. The spirit of experiment rather than appeal to authority was in the air. An evidence of this new attitude is seen in the founding of the Royal Society, whose motto, *Nullius in verba,* Professor Andrade delightfully translates as "We don't take anybody's word for it." Into this changing scientific world Newton was

born. His was the greatest figure, but there were many lesser scientists united in the crusade to dethrone the appeal to authority and substitute the appeal to observation and experiment.

A character in one of George A. Birmingham's novels remarks: "The things that are told about the boyhood of great men are all invented afterwards. Nobody expects them to be true: but biographers have to put them in to satisfy the curiosity of the public." We are spared such stories in Newton's case. His youth was undistinguished, with no indication of genius. He was clever at drawing and handicrafts, skills which later stood him in good stead. Even as a student at Cambridge he gained no distinction, but there he studied under Isaac Barrow, Lucasian professor of mathematics, whose influence was important in shaping Newton's career.

Then came the period which the author entitles "Meditations at Woolsthorpe." The spread of the Great Plague caused the closing of the Cambridge colleges in 1665, and the students were sent away. At his family home of Woolsthorpe, Newton, at the age of 22 and 23, "meditated" for about 18 months. The nature of his cogitations is probably the most astonishing feature of his life, for he then laid the groundwork for most of his later discoveries. The author sums up the achievements of this year and a half: "The young Newton mastered the basic laws of mechanics; convinced himself that they applied to heavenly as well as to earthly bodies, and discovered the fundamental law of gravitational attraction; invented the methods of the infinitesimal calculus; and was well on the way to his great optical discoveries. What he did later went, of course, immensely further, but it all grew out of the results won in that wonderful period, it was all built on the foundations then laid."

From the time of his return to Cambridge in 1667 Newton's public life in the field of science began. The author takes us through one achievement after another, in each case giving a clear and simple explanation of what the discovery means. He also describes the preliminary work done in each field by Newton's predecessors, the data Newton had to go on. As Newton himself is said to have remarked, "If I have seen farther than most men, it is by standing on the shoulders of giants."

To those who are astronomically minded, the most interesting story in the book concerns the establishment of the universal law of gravitation. The Greek philosophers taught that there is a complete distinction between celestial and terrestrial bodies: they differ in substance and behavior, and there is no use trying to explain the movements of planets on the basis of laws discovered for bodies on the earth. In Newton's day this distinction was being questioned. Johann Kepler had worked out the traffic rules of the solar system, and the planets did not seem to be such unfamiliar bodies as they had previously been considered. It was obvious that these traffic rules should be explainable by some attractive force vested in the sun. If there is such a force, it must be weakened by distance, but the rate of weakening was unknown.

During his Woolsthorpe period Newton had almost succeeded in proving mathematically that a force of attraction that obeyed the inverse square law would explain equally the moon's orbit around the earth and the power of the earth's attraction for objects at its surface—a universal force. It worked out, as he later admitted, "pretty nearly." Curiously, Professor Andrade does not mention one probable reason the calculations did not come out exactly—a wrong value for the size of the earth—as is stated by other historians of science (Dampier, Jeans, Butterfield). When later the French scientist Picard announced a revised value for the earth's size, and Newton reworked his calculations on this basis, the mathematics came out perfectly.

By 1684, Robert Hooke, Edmond Halley, and Christopher Wren were working on the problem of the sun's attractive force to explain planetary motions, and suspected that this obeyed the inverse square law. They did not possess the mathematical ability to complete a proof and consulted Newton, who immediately said that he had already obtained the proof but had lost the record. It was then that he reworked the problem. This incident led to the preparation and publication in 1687 of the *Principia*.

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Principia resulted in exhaustion so great that Newton suffered a complete nervous breakdown. He turned against science and, when recovered, sought an administrative job. This was found for him in 1696 as warden of the mint in London, and three years later he became master of the mint, a position he held until his death in 1727. This was no sinecure, as there were very real administrative problems to solve, and Newton became an efficient man of affairs.

During this last period of his life Newton eventually resumed his interest in science, publishing his *Opticks* in 1704. Professor Andrade gives a useful summary of its contents. Newton was also president of the Royal Society from 1703 until his death. He collected a large library of religious books and wrote on theology and biblical interpretation.

Throughout the book Newton's personality stands out under the author's skillful handling. Newton's achievements are attributed to two qualities in particular which he possessed in an unusual degree —his great power of mental concentration, and his ability to foresee scientific truths before he demonstrated them. With regard to the latter, all the greatest scientists seem to have been able to reach conclusions by a kind of intuition.

The character of Newton was a mixture of strange and often contradictory qualities. He did his work for his own satisfaction and published it only when his friends bullied him into action—probably, in Professor Andrade's opinion, because it always seemed that publication involved him in subsequent controversy which he loathed. He was unjust in withholding credit to others for their previous work (this resulted in bitter disputes with Robert Hooke and the Rev. John Flamsteed, Astronomer Royal), but was generous and kindly to young scientists with whom he came in contact. He was irritable and overbearing, a difficult man who shunned society, yet even when famous he gladly mixed with country friends of his youth. He was devoted to his mother, constituting himself her nurse in her last illness.

If the note of adulation is sounded very often in this book, the reader should realize the pinnacle on which Newton was set even in the opinion of his contemporaries. It was expressed in Alexander Pope's couplet,

Nature and Nature's laws lay hid in night:
God said, "Let Newton be!" and all was light.

E. RUSSELL PATERSON
Sir George Williams College
Montreal, P. Q.

NEW BOOKS RECEIVED

RELATIVITY FOR THE LAYMAN, *James A. Coleman*, 1954, *William-Frederick Press*. 131 pages. $2.75.

The author, who is professor of physics at Connecticut College, presents in simple language the background of relativity, the content of the theory itself, and the observational and experimental proofs of relativity.

FIELD BOOK OF THE SKIES, *William T. Olcott*, revised by *R. Newton Mayall* and *Margaret W. Mayall*, 1954, *Putnam's*. 482 pages. $5.00.

This is the fourth edition of a well-known handbook for the amateur astronomer that first appeared in 1929. Intended for the observer with a small telescope, field glasses, or the unaided eye, the book gives star maps and lists of telescopic objects for individual constellations visible from north temperate latitudes. There are maps of the moon and descriptions of its more conspicuous features.

ASTRONOMY IN THE UNIVERSITY OF TORONTO, *C. A. Chant*, 1954, *University of Toronto Press*, Toronto 5, Canada. 66 pages. $2.00, paper bound.

The foreword by Sidney Smith states, "This little book is a chapter in a full autobiography of Professor Chant which we hope will soon be published." It tells the story, beginning with a tour of inspection to American observatories in 1905, that led to the opening in 1934 of the David Dunlap Observatory with its 74-inch reflector.

HIMMELSWUNDER IN FELDSTECHER, *Rudolf Brandt*, 4th edition 1954, *Johann Ambrosius Barth*, Salomonstr. 18 B, Leipzig C 1, Germany. 119 pages. DM 3.75, paper bound.

The Wonders of the Sky in a Field Glass is a small manual in German, for amateur astronomers, that tells how to select and test field glasses, and what they will show of the sun, moon, planets, double stars, clusters, and nebulae. There are lists of objects and finder charts.

THE OBSERVER'S HANDBOOK FOR 1955, edited by *C. A. Chant* and *Ruth J. Northcott*, 1954, *Royal Astronomical Society of Canada*, 13 Ross St., Toronto. 78 pages. 50¢, paper bound.

The *Observer's Handbook*, now in its 47th year, contains tables for the rising and setting of the sun and moon; a list of the astronomical phenomena for each day of 1955; predictions for Jupiter's satellites and for lunar occultations; tables of data on planets and satellites; lists of stars, clusters, nebulae, and galaxies; together with other useful astronomical information.

DEVELOPMENT OF THE GUIDED MISSILE, *Kenneth W. Gatland*, 2nd edition, 1954, *Philosophical Library*. 292 pages. $4.95.

Mr. Gatland is a British aircraft design engineer and writer on rocketry. Following an account of rocket motors and propellants, he takes up detailed descriptions of antiaircraft missiles, air-to-air missiles, guided bombs, and long-range rockets. Three chapters deal with rockets for high-altitude research, space satellites, and interplanetary flight.

There are numerous photographs, and many tables of numerical data. An appendix lists the characteristics of 140 powered missiles. While this book can be read with profit by the interested layman, the references to rocket literature and the numerous engineering details should make it useful to the specialist as well.

THE MATHEMATICAL PRACTITIONERS OF TUDOR AND STUART ENGLAND, *E. G. R. Taylor*, 1954, *Cambridge University Press*. 443 pages. $9.50.

This work deals with the history of science in England from 1485 to 1714. The term "mathematical practitioner" includes astronomers, instrument makers, navigators, surveyors, and map makers, as well as writers on and teachers of mathematics. Biographical sketches of 582 of these men are given, and descriptions of 628 books written by them.

UNITRON

You really surprised us! Our mailbag has been bulging with wonderful name suggestions for our new Rotary Eyepiece Selector. While it wasn't our intention to formalize this into a contest, we have been flooded with "entries," and do not need any more. We're carefully considering each suggestion—and we'll have a name soon.

Here are some of the comments which accompanied the proposed names. Some of the names themselves will be published next month.

"I wish you'd stop advertising. It has gotten to the point where the first thing I look at is the UNITRON advertising. Being a college student, therefore broke, I have to be content with drooling over telescopes I can't afford at the present time."
E.N.Y., Albany, Minn.

"My budget won't permit such an instrument as a UNITRON. But I could not help finding interest in your ad in the January issue. I do not even know whether I am eligible to suggest a name for your revolving eyepieces, but here are a few that come to mind . . . an ATM can always use a good piece of optical equipment."
V.B.R., Spokane, Wash.

"I think the Rotary Eyepiece Selector will be a great addition to a telescope."
F.H., Jr., Ephrata, Pa.

". . . a wonderful accessory . . ."
G.E., Quebec, Canada

"Received my magazine, and that honey of a 6" on the back cover smacked me right in the eye . . . Reading further, I saw your fine idea for a multiple eyepiece selector."
R.F.L., Manitowoc, Wisc.

"My 3" UNITRON has made a refractor fan out of me. It's a dandy little instrument and precision-plus right to the edges . . . I'm watching the 6" Refractor with intense interest . . ."
M.A.S., Escondido, Calif.

"That Rotary Eyepiece Selector is a wonderful idea."
S.E.P., Truth Or Consequences, N.M.

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R.L.K., Brockport, N.Y.

"I wish to congratulate you on the supreme quality of your telescope. The college which I attend has your 3" Equatorial . . . the quality and performance of this product is certainly excellent. I plan to buy one soon."
T.W.W., Huntington, W. Va.

"I find your interesting and informative advertising a worthwhile part of **Sky and Telescope**, and look forward every month to see what new details you will be showing . . ."
P.L., Seattle, Wash.

"We are very pleased with the new UNITRON we purchased just before Christmas . . . We feel that the new Rotary Eyepiece Selector would be an additional improvement that everyone would enjoy."
J.K.W., Charlotte, Mich.

"I was pleased with your projected items for 1955 . . ."
W.A.M., Roselle Park, N. J.

(See page 208 and the back cover)

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Every UNITRON owner will certainly want to add this valuable accessory to his telescope. With the Rotary Eyepiece Selector, you have 6 magnifications at your fingertips. There is no need to fumble for eyepieces in the dark. To change magnifications, merely rotate a new eyepiece into position while the object stays centered in the field of view.

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Orders are now being accepted for delivery at the end of March. Since the initial demand is certain to exceed production, we suggest that you write at once to reserve your Selector and thereby insure earliest delivery. Payment should not be sent until delivery time. Please address your order to Dept. RS.

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UNITRON Rotary Eyepiece Selector
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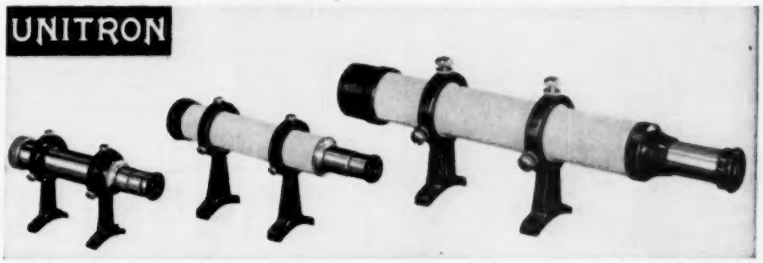

L. to R.: (1) 23.5-mm. 6x finder; (2) 30-mm. 8x finder; (3) 42-mm. 10x finder

1. **VIEW FINDER** (As used on UNITRON 2.4" Equatorial): 23.5-mm. (.93") achromatic objective, 6x eyepiece with crosshairs. Chromed brass tube. Mounting brackets with centering screws. **Only $8.50 postpaid**

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54 mm (2⅛")	330 mm (13")	12.50	83 mm (3¼")	711 mm (28")	28.00
54 mm (2⅛")	390 mm (15.356")	9.75	83 mm (3¼")	762 mm (30")	28.00
54 mm (2⅛")	508 mm (20")	12.50	83 mm (3¼")	876 mm (34½")	28.00
54 mm (2⅛")	600 mm (23½")	12.50	83 mm (3¼")	1016 mm (40")	30.00
78 mm (3 1/16")	381 mm (15")	21.00	110 mm (4⅜")*	1069 mm (42 1/16")	60.00
81 mm (3 3/16")	622 mm (24½")	22.50	110 mm (4⅜")	1069 mm (42 1/16")	67.00

*Not coated

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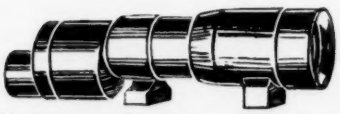

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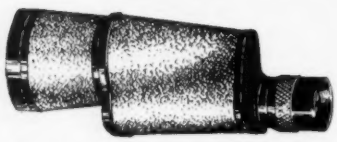

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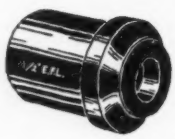

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GLEANINGS FOR ATM's

EDITED BY EARLE B. BROWN

NOTES ON BASIC OPTICS—XII

M. Aberrations of Lenses

Our January discussion of lenses can be extended to take up the finer properties of lenses, and to show why optical design is difficult and laborious. We had derived the rather simple Equation 26, which gives the focal length of a lens in terms of the radii of its surfaces and the refractive index of the glass. This formula works very nicely if the conditions we stipulated are met—all the light rays lie very close to the optical axis and are nearly parallel to it. This amounts to a pinhole-sized aperture, with object and image points on the axis. If lenses behaved according to this equation for large apertures and for points off the axis, lens design would be absurdly simple.

In our ray tracing in the last installment, Equations 16 to 19 were derived by strict application of trigonometry to a curved refracting surface, and they represent the exact performance of such a surface. These are the equations that tell us what a ray of light really does. As the aperture and field of view of an optical system approach zero, the imagery approaches that described by Equations 16a through 19a.

Hence we may speak of the ideal imagery described by the latter, simplified equations, and the actual imagery described by the exact equations. The difference between the results of the two sets of equations is the **aberration** of the system.

In the ideal imagery all rays from a given object point are eventually reunited at one image point. The actual rays fail in general to do this, and each type of failure to meet the required image point is a specific aberration.

If we try to combine the exact equations for two refracting surfaces in series, an unmanageably complex equation results. For more than two surfaces it would be hopeless. Hence we are forced to an indirect method for designing complicated optical systems. First we arbitrarily choose kinds of glass and radii of curvature, and compute from the exact equations how the rays actually come out. Comparison with the simplified equations tells what the aberrations are. We then go back and make another slightly different choice and try again. Thus by trial and error we can arrive at an acceptable design. For a simple lens, such as a telescope objective, this is not a difficult process, but for a complex system with a dozen or more surfaces it becomes quite involved. Of course, when we make changes for a new trial, past experience and a knowledge of the probable effect of such changes helps a lot.

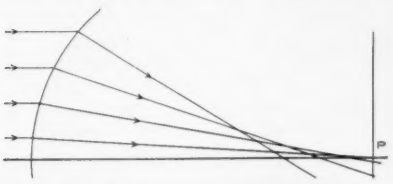

Fig. 40. Spherical aberration.

1. **Spherical Aberration.** First consider an object point and image point on the optical axis. There are two aberrations that affect axial image points: spherical aberration and chromatic aberration.

The only difference between the actual and the simplified ray-tracing equations is that the latter assume the sine of an angle to be equal to the angle itself (measured in radians). This is very nearly true for small angles, and the difference is only one per cent at 15°. However, as the angle gets larger, the disparity between angle and sine increases, and the actual ray departs more and more from the ideal ray. This is shown in Fig. 40 for a positive refracting surface. The farther an incident ray is from the axis, the closer to the lens is the intersection of the refracted ray and axis.

We draw the paraxial image plane through the point **P**, where the simplified equations tell us that rays very close to the axis are focused. Now, the amount by which each ray falls short of the par-

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axial image plane is called the **spherical aberration** of that ray (strictly, the longitudinal spherical aberration). If the ray falls to the left of the paraxial image plane, the spherical aberration is positive in sign, and the surface is **undercorrected;** if the ray falls to the right, the

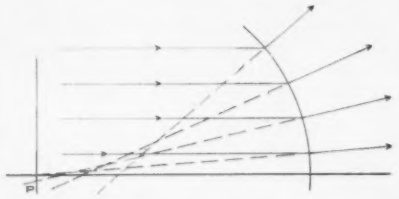

Fig. 41. Negative spherical aberration.

spherical aberration is negative, and the surface is **overcorrected.** Fig. 41 shows the case of a negative refracting surface, and the aberration is negative.

We could compute the shape of a single refracting surface that would have no spherical aberration for a given object point, but the aberration would not be zero for other object points. For off-axis object points such a surface would be particularly objectionable. In modern lens design, however, nonspherical lens surfaces are often used to correct spherical and other aberrations. Parabolic surfaces, in particular, are frequently used.

The spherical aberration given by an optical element can be either positive or negative, depending on the positions of the object and image points. Obviously, a lens system can be corrected for this aberration by combining surfaces of positive and negative curvature so that their separate contributions to the spherical aberration add to zero. In general, we cannot bring all the rays to an exact focus; the best that can be done is to minimize the departure from perfection.

Equation 26 gave the focal length of a thin lens in terms of its refractive index and the radii of curvature of the lens surfaces. We can rewrite this as:

$$f = (n - 1)(c_1 - c_2), \qquad (26a)$$

where $c = 1/r$, and is called the **curvature** of the surface. Clearly, we can redistribute the curvature between the two surfaces without changing the focal length. Thus, all the lenses in Fig. 42 have the same focal length, but different distributions of curvature. This procedure, called "bending" a lens, is the most powerful means for correcting spherical aberration.

2. **Chromatic Aberration.** The second type of aberration which affects axial images is chromatic aberration. This arises from the fact that the index of refraction is not the same at all wave

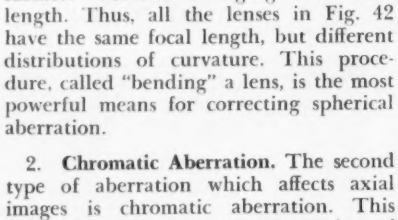

Fig. 42. Lenses of equal focal lengths.

lengths. Therefore, the focal lengths for different colors of light are different. As a result, a simple lens will give images for each color distributed along the optical axis, the violet image nearest the lens, the red image farthest away. When we look at an image of a star made by a lens which is uncorrected for chromatic aberration, we see a central core formed of the color that happens to be in focus, surrounded by a halo of the other colors which are out of focus.

Since chromatic aberration comes from a property of the glass itself, it cannot be corrected by varying curvatures or thicknesses. The only way is by combining two or more kinds of glass. The difference between the refractive indexes for two different colors of light is called the **dispersion** of a particular kind of glass. By combining a positive lens of low dispersion and a negative lens of high dispersion, an **achromatic lens** results. In general, glasses with high refractive indexes have high dispersions, and low indexes go with low dispersions. Were the dispersions of all glasses exactly proportional to their indexes, any attempt to correct

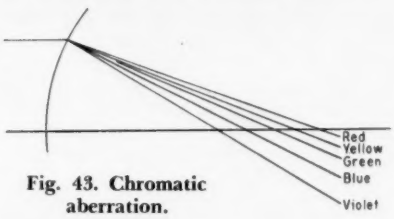

Fig. 43. Chromatic aberration.

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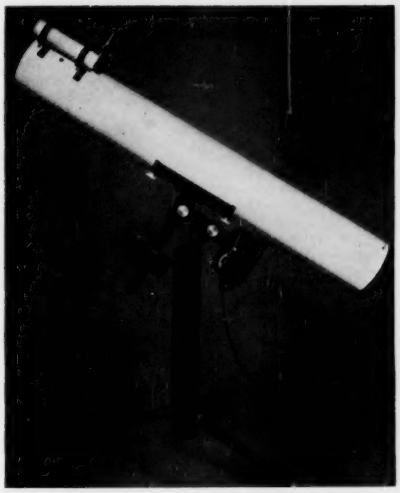

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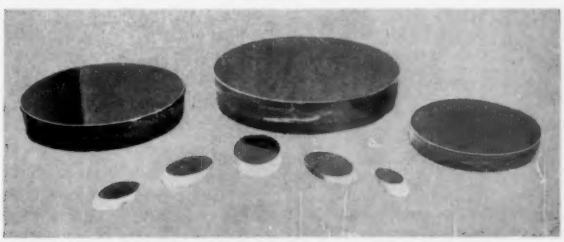

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chromatic aberration would result in a lens of zero power. Fortunately, a difference in index of 10 per cent is usually combined with a difference in dispersion of the order of 30 per cent. Hence a weak negative lens and a strong positive lens can be combined to give an achromatic lens with net positive power.

Fig. 43 illustrates the chromatic aberration of a positive lens. If the violet focus is to the left of the red focus, the chromatic aberration is positive; if the reverse is true, the aberration is negative. The terms undercorrection and overcorrection, with reference to chromatic aberration, mean positive and negative aberrations, respectively.

A combination of positive and negative lenses of different kinds of glass will, in general, bring only two specific wave lengths to the same focus; the rest of the spectrum is still spread out along the axis. However, this spread is much less than if the chromatic aberration were uncorrected, and for most purposes this degree of correction will suffice. The spread of the colors along the axis which remains after two specified colors have been brought to a common focus is the **secondary spectrum.** As a general rule, three kinds of glass are needed to bring three colors to the same focus. A lens of this construction is known as an **apochromatic lens;** it is a type widely used in photography and in microscopy.

(To be continued)

A HINT FOR TELESCOPE USERS

Cleaning Mirrors. The aluminum coating on a mirror is indeed soft, and would be badly scarred if rubbed with dry absorbent cotton. An oft-laundered bath towel or face cloth is freer from minute particles of grit or bits of lint. The cloth should be washed again just before use.

Take the mirror out of its cell. Prepare a mild solution of Dreft or a similar detergent. Dip a tuft of the cloth into the solution and, holding the mirror on edge, gently rotate the tuft on the mirror surface without applying any pressure. Afterward, with the mirror still on edge, rinse off the cleansing solution with distilled water poured onto the top of the mirror. Distilled water is best, but if tap water must be used, professional opticians add to it a wetting agent (such as used in photographic darkrooms) to avoid leaving a mineral residue.

If there are a few streaks or water droplets after rinsing, they can be taken off with a dry tuft of the cloth, applied without pressure. Gentle use of the cloth is necessary throughout the process to avoid scratches from airborne grit.

Frequent cleaning is unnecessary if dust is prevented from settling on the mirror. If you have a portable reflector whose tube is taken indoors when not in use, store it in a dry closet upside down, with the mirror end on top.

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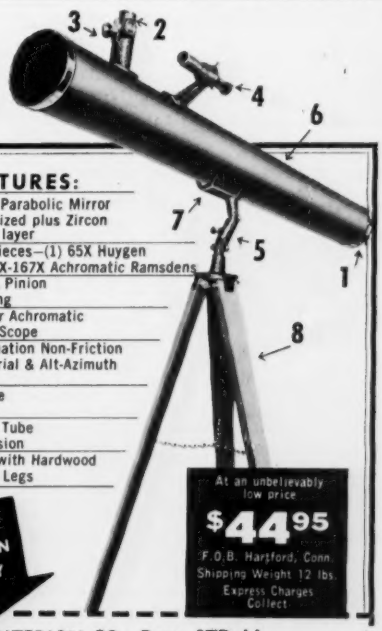

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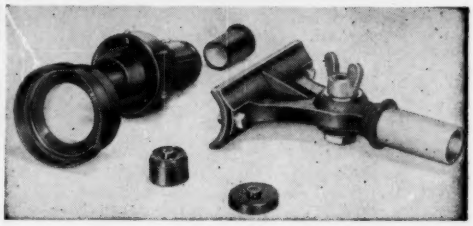

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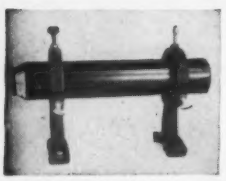

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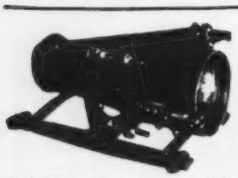

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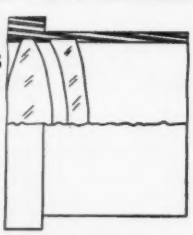

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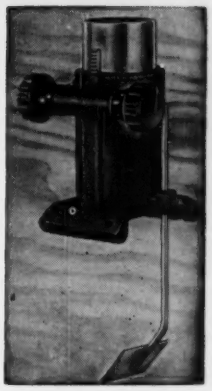

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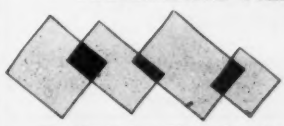

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OBSERVER'S PAGE

Universal time is used unless otherwise noted.

Observing Eclipses of Jupiter's Satellites

SOME ECLIPSE OBSERVING need not require the long journeys many persons made last June for the total eclipse of the sun. In fact, during March alone, most American observers will have nearly a dozen opportunities to watch eclipses of another sort—those of Jupiter's satellites. A telescope of at least two inches aperture is needed, and more than about 40 power; also, the observer must know when to look.

As an example, suppose that you had Jupiter under view on the late evening of March 9th. The accompanying chart of Jupiter satellite configurations is for 4:30 a.m. at Greenwich (Universal time). Therefore, the positions shown for March 10th correspond to those at 11:30 p.m. Eastern standard time in the United States on March 9th.

Only three satellites will be visible. As seen in an inverting telescope, satellites **I** and **III** are to the left of the planet's disk, and **IV** is to the right. Satellite **II** is not visible, as it has passed behind Jupiter and will not reappear from its shadow until 1:31 a.m. EST, March 10th.

To tell exactly where **II** will reappear, consult the small diagrams labeled *Phases of the Eclipses of the Satellites*, noting the position marked *r*. Watch this spot carefully; at about 1:30 a.m. a very minute speck of light will appear there. It will brighten rapidly, and in about three minutes **II** will have reached its normal full brightness, entirely clear of the planet's shadow.

Reappearances of the other satellites proceed similarly, more rapidly in the case of **I**, more slowly for **III**, while **IV** brightens very gradually.

For **I** and **II**, only reappearances from the shadow are visible in March. This is because Jupiter passed opposition in January; hence the western edge of the shadow cone, where these satellites enter the shadow, is now behind the planet. Before opposition the situation was reversed; then the eastern edge of the shadow was hidden by Jupiter, and only disappearances of **I** and **II** were then visible.

The diagram shows that complete eclipses can now be observed for **III**, as on March 20-21. Because of its great distance from Jupiter, satellite **IV** can normally be watched at both disappearance and reappearance in the same eclipse. The observing of complete eclipses is rare for **II** and impossible for **I**.

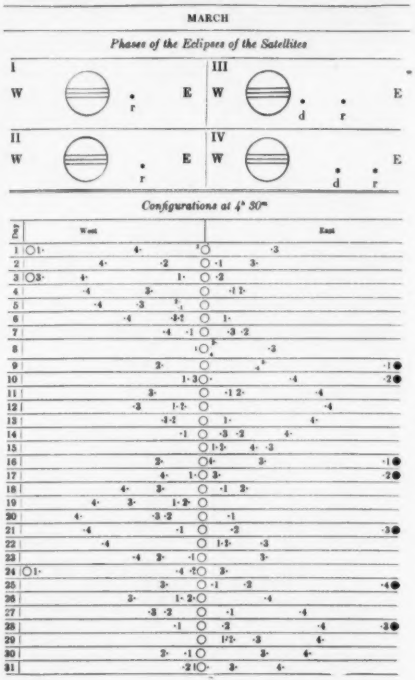
The eclipse phenomena visible in the United States and Canada are listed here from the *American Ephemeris*. The times are EST, and may differ by several minutes from the actual moments of first or last visible speck. It is always well to be at the telescope a few minutes before the time of an expected eclipse event. Reappearances are indicated by R, disappearances by D.

March 1, **I**, R, 10:56 p.m.; 2, **II**, R, 10:56 p.m.; 9, **I**, R, 0:51 a.m.; 10, **II**, R, 1:31 a.m.; 13, **III**, R, 10:43 p.m.; 16, **I**, R, 2:47 a.m.; 17, **I**, R, 9:16 p.m.; 20, **III**, D, 11:09 p.m.; 21, **III**, R, 2:44 a.m.; 24, **IV**, D, 10:09 p.m., **I**, R, 11:11 p.m.; 25, **IV**, R, 2:31 a.m. (near Jupiter setting for the Atlantic coast). J. A.

JUPITER'S SATELLITES

The configurations of Jupiter's four bright moons are shown below, as seen in an astronomical or inverting telescope, with north at the bottom and east at the right. In the upper part, *d* is the point of disappearance of the satellite in Jupiter's shadow; *r*, the point of reappearance.

In the lower section, the moons have the positions shown for the Universal time given. The motion of each satellite is from the dot to the number designating it. Transits over Jupiter's disk are shown by open circles at the left, eclipses and occultations by black disks at the right. The chart is from the *American Ephemeris and Nautical Almanac*.



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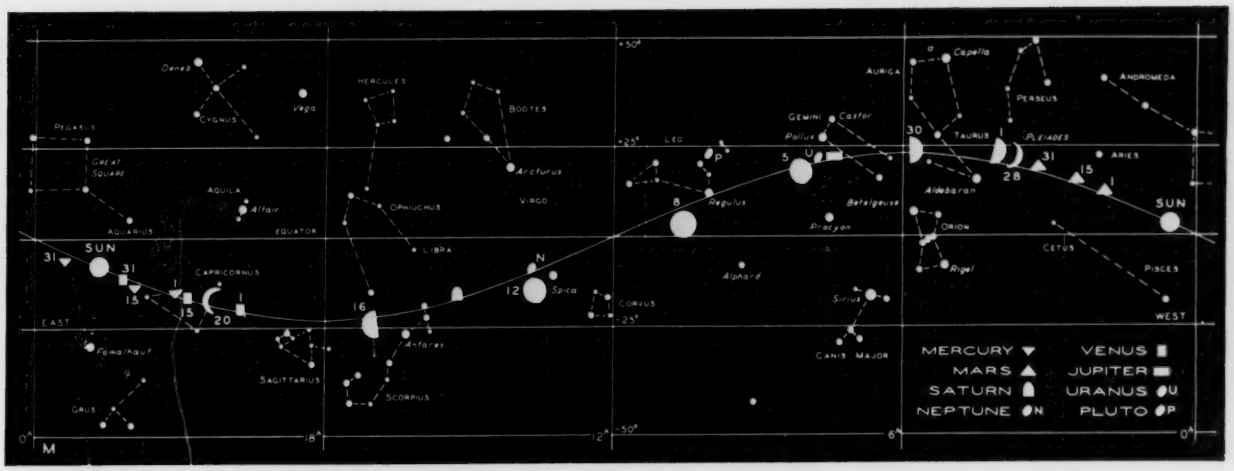


THE SUN, MOON, AND PLANETS THIS MONTH

The sun, on the ecliptic, is shown for the beginning and end of the month. The moon's symbols give its phase roughly, with the date marked alongside. Each planet is located for the middle of the month and for other dates shown.

Mercury, in the morning sky, reaches greatest elongation on March 11th, 27° 27′ west of the sun. Although this is nearly as far from the sun as Mercury can be, the southern declination of the planet is a disadvantage to observers in mid-northern latitudes, for whom the planet rises only an hour before the sun. South of the equator, the interval can be twice as long. At elongation, Mercury appears at +0.4 magnitude. It is best seen at this apparition during the first two weeks of March.

Venus, also a morning object, rises 1¾ hours before the sun in midmonth, as observed from latitudes around 40° north. This brilliant planet is at magnitude −3.6 on March 15th, when its gibbous disk has an apparent diameter of 16″.

Earth will arrive at heliocentric longitude 180° on March 21st at 9:36 UT. Spring begins in the Northern Hemisphere and autumn south of the equator, with days and nights approximately equal over the earth.

Mars travels through Aries in March, continuing to decrease in brightness. On the 15th, its magnitude is +1.6, and it sets four hours after the sun.

Jupiter continues to dominate the evening sky, at magnitude −2.0 in early March. On the 16th, Jupiter resumes eastward motion among the stars. Located in eastern Gemini, the planet is high on the meridian as twilight ends, and sets before Venus rises in the morning. The Jovian disk appears 41″ in equatorial diameter on the 15th, a fine object in small telescopes.

Saturn, located in central Libra, rises about 10:30 p.m. local time in mid-March. Retrograde motion commences March 1st. The ring system presents its northern face, inclined 22°.2 to our view on the 15th, when Saturn shines at magnitude +0.6.

Uranus is in retrograde motion in eastern Gemini. It is of the 6th magnitude, and is about 4° east of Jupiter. A chart of its path in 1955 appeared on page 169 last month.

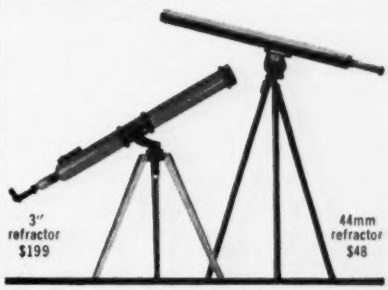
Neptune may be viewed with the aid of binoculars after evening twilight ends. This distant planet is in retrograde motion in eastern Virgo, about 5° east of Spica. A chart of its path during 1955 appeared on page 169 last month.

E. O.

SUNSPOT NUMBERS

December 1-2, 0, 0; 3, 1, 0; 4, 3, 0; 5, 1, 0; 6, 0, 0; 7, 3, 0; 8-10, 0, 0; 11, 1, 0; 12-13, 0, 0; 14, 3, 0; 15, 18, 11; 16, 17, 18; 17, 19, 17; 18, 26, 14; 19, 19, 19; 20, 16, 19; 21, 5, 14; 22, 5, 7; 23, 14, 7; 24, 12, 15; 25, 8, 10; 26, 5, 7; 27, 0, 0; 28, 5, 0; 29, 14, 13; 30, 21, 29; 31, 22, 25. Means for December: 7.7 American; 7.3 Zurich.

Above are given the date, the American number, then the Zurich number. These are observed mean relative sunspot numbers, the American computed by D. W. Rosebrugh from AAVSO Solar Division observations, the Zurich numbers from Zurich Observatory and its stations in Locarno and Arosa.



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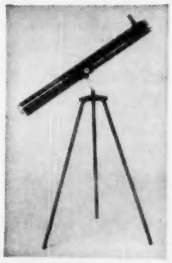

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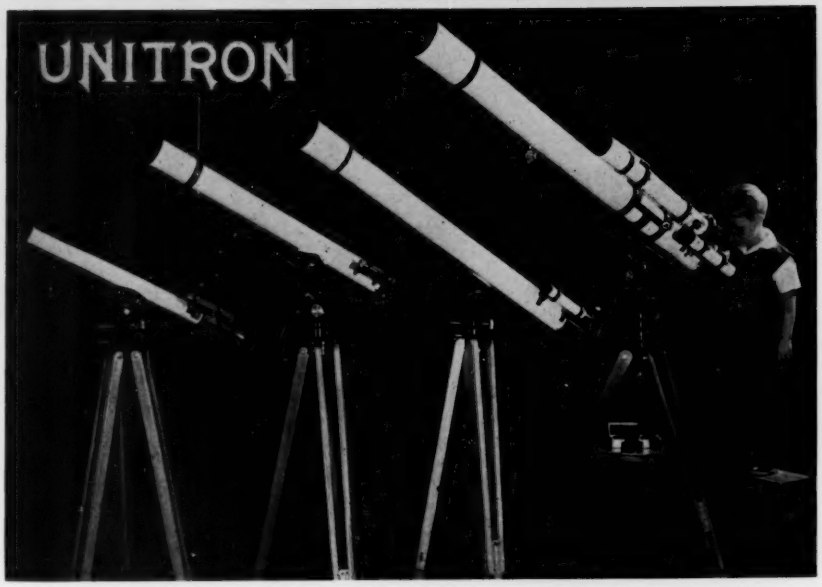

The UNITRON Refractors, left to right, are the 1.6" Altazimuth, the 2.4" Equatorial, the 3" Altazimuth, the 4" Photo-Equatorial, with a young observer.

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(See page 197 and the back cover)

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VARIABLE STAR MAXIMA

March 5, S Ursae Majoris, 123961, 7.9; 7, R Phoenicis, 235150, 7.8; 9, S Canis Minoris, 072708, 7.5; 15, R Centauri, 140959, 5.9; 16, T Centauri, 133633, 6.1; 18, R Cygni, 193449, 7.3; 21, T Cassiopeiae, 001755, 7.8; 21, R Carinae, 092962, 4.6; 25, T Normae, 153654, 7.4; 27, R Caeli, 043738, 8.0; 27, U Orionis, 054920a, 6.6; 28, R Draconis, 163266, 7.6; 31, V Coronae Borealis, 154639, 7.4. Apr. 2, R Leporis, 045514, 6.7; 5, RS Cygni, 200938, 7.4; 7, R Geminorum, 070122a, 7.1.

These predictions of variable star maxima are by the AAVSO. Only stars are included whose mean maximum magnitudes are brighter than magnitude 8.0. Some, but not all of them, are nearly as bright as maximum two or three weeks before and after the dates for maximum. The data given include, in order, the day of the month near which the maximum should occur, the star name, the star designation number, which gives the rough right ascension (first four figures) and declination (bold face if southern), and the predicted magnitude.

MOON PHASES AND DISTANCE

First quarter	March 1,	12:40
Full moon	March 8,	15:41
Last quarter	March 16,	16:36
New moon	March 24,	03:42
First quarter	March 30,	20:10
Full moon	April 7,	06:35

March			**Distance**	**Diameter**
Apogee	14,	21h	251,300 mi.	29′ 33″
Perigee	26,	16h	226,400 mi.	32′ 48″
April				
Apogee	11,	14h	251,800 mi.	29′ 29″

MINIMA OF ALGOL

March 3, 13:00; 6, 9:49; 9, 6:38; 12, 3:28; 15, 0:17; 17, 21:06; 20, 17:55; 23, 14:44; 26, 11:33; 29, 8:23. April 1, 5:12; 4, 2:01; 6, 22:50; 9, 19:39.

These minima predictions for Algol are based on the formula in the 1953 *International Supplement* of the Krakow Observatory. The times given are geocentric; they can be compared directly with observed times of least brightness.

OCCULTATION PREDICTIONS

March 2-3 **Mu Geminorum** 3.2, 6:20.2 +22-32.3, 9, Im: **D** 7:27.1 +0.1 −1.1 84; **E** 7:32.6 +0.1 −1.4 103; **F** 7:47.7 +0.3 −1.8 131; **H** 7:40.2 +0.2 −2.9 152; **I** 7:07.4 −0.6 −2.0 119. Em: **H** 8:23.9 −1.0 −0.2 240; **I** 8:09.2 −0.6 −1.4 270.

March 30-31 **Zeta Geminorum** 3.7-4.1, 7:01.4 +20-38.3, 7, Im: **A** 5:33.1 +0.2 −1.5 110; **B** 5:28.9 +0.1 −1.5 106; **C** 5:39.7 +0.3 −1.6 121; **D** 5:32.5 +0.1 −1.6 115; **E** 5:40.3 +0.1 −2.0 134; **F** 6:05.9 +1.1 −3.8 173; **I** 5:13.2 −0.3 −3.1 156.

For stations in the United States and Canada, usually for stars of magnitude 5.0 or brighter, data from the American Ephemeris and the British Nautical Almanac are given here, as follows: evening-morning date, star name, magnitude, right ascension in hours and minutes, declination in degrees and minutes, moon's age in days, immersion or emersion; standard station designation, UT, a and b quantities in minutes, position angle on the moon's limb; the same data for each standard station westward.

The a and b quantities tabulated in each case are variations of standard-station predicted times per degree of longitude and of latitude, respectively, enabling computation of fairly accurate times for one's local station (long. Lo, lat. L) within 200 or 300 miles of a standard station (long. LoS, lat. LS). Multiply a by the difference in longitude (Lo — LoS), and multiply b by the difference in latitude (L — LS), with due regard to arithmetic signs, and add both results to (or subtract from, as the case may be) the standard-station predicted time to obtain time at the local station. Then convert the Universal time to your standard time.

Longitudes and latitudes of standard stations are:

A	+72°.5,	+42°.5	**E**	+91°.0,	+40°.0
B	+73°.6,	+45°.5	**F**	+98°.0,	+31°.0
C	+77°.1,	+38°.9	**G**	Discontinued	
D	+79°.4,	+43°.7	**H**	+120°.0,	+36°.0
			I	+123°.1,	+49°.5

UNIVERSAL TIME (UT)

TIMES used on the Observer's Page are Greenwich civil or Universal time, unless otherwise noted. This is 24-hour time, from midnight to midnight; times greater than 12:00 are p.m. Subtract the following hours to convert to standard times in the United States: EST, 5; CST, 6; MST, 7; PST, 8. If necessary, add 24 hours to the UT before subtracting, in which case the result is your standard time on the day preceding the Greenwich date shown.

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The asteroid 29 Amphitrite among the stars of Taurus, photographed by J. B. Downs, Jr., at 10:30 p.m. EST on November 20, 1954, and at 9.45 p.m. the next night (inset). The scale of the field is given by the Pleiades cluster in the lower right. Bright stars in the upper right are Zeta and Omicron Persei. The asteroid's images are marked by short vertical lines. Amphitrite moved 14′ westward between exposures, made five and four days before opposition.

PHOTOGRAPHING AN ASTEROID

Taking the predicted positions of the asteroid 29 Amphitrite from the ephemeris in the November issue of *Sky and Telescope,* I plotted them on Webb's *Atlas,* and photographed this region of the sky on November 20th and 21st.

The camera has an f/4.5 enlarging lens of 8½-inch focal length, and is attached to my 8-inch reflector which I use for guiding. Both exposures were 35 minutes on Tri-X-Pan film.

It was a real thrill when the prints were made to find the tiny asteroid on each photograph, clearly identified by its motion. The actual position of Amphitrite does not exactly coincide with my plot of the ephemeris.

J. B. DOWNS, JR.
1632 Pershing Rd.
Jacksonville, Fla.

ED. NOTE: The asteroid predictions in *Sky and Telescope* are approximate, and occasionally differ from observation by 15′ or more.

PREDICTIONS OF BRIGHT MINOR PLANET POSITIONS

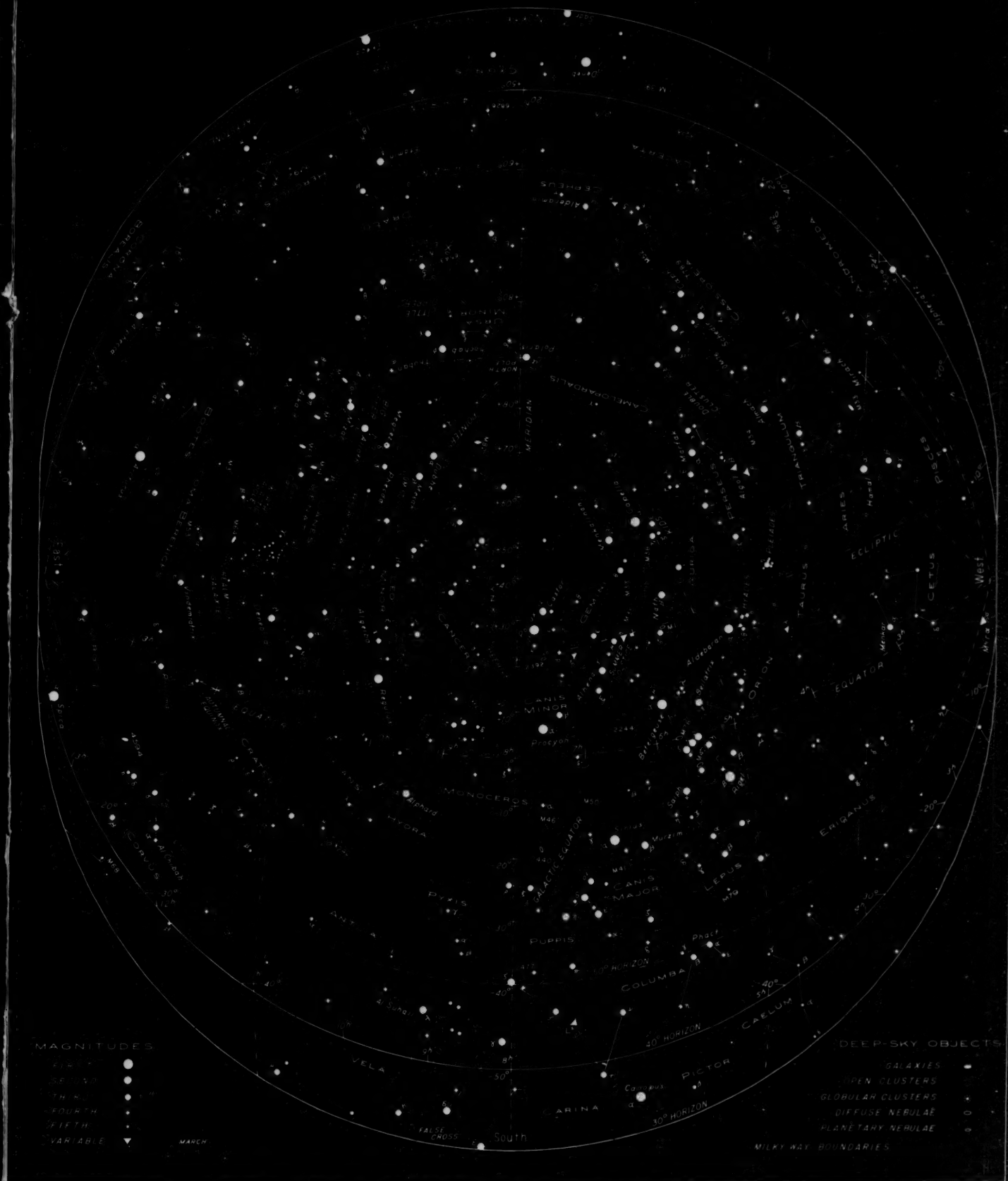
Massalia, 20, 8.9. March 4, 12:39.0 −4·47; 14, 12:31.5 −3·56; 24, 12:22.5 −2·56. Apr. 3, 12:13.4 −1·53; 13, 12:05.3 −0·57; 23, 11:59.3 −0·13.

Hygiea, 10, 9.1. March 4, 13:02.9 −12·32; 14, 12:57.9 −12·16; 24, 12:51.4 −11·46. Apr. 3, 12:44.0 −11·05; 13, 12:36.5 −10·17; 23, 12:29.8 −9·27.

Harmonia, 40, 9.5. March 14, 13:29.2 −1·53; 24, 13:22.0 −0·56. Apr. 3, 13:13.0 +0·04; 13, 13:03.3 +1·00; 23, 12:54.1 +1·44. May 3, 12:46.6 +2·10.

After the asteroid's name are its number and the magnitude expected at opposition. At 10-day intervals are given its right ascension and declination (1955.0) for 0h Universal time. In each case the motion of the asteroid is retrograde. Data are supplied by the IAU Minor Planet Center at the University of Cincinnati Observatory.

SOUTH
HORIZON
HORIZON
HORIZON



STARS FOR MARCH

The sky as seen from latitudes 30° to 50° north, at 9 p.m. and 8 p.m., local time, on the 7th and 23rd of March, respectively; also, at 7 p.m. on April 7th. For other dates, add or subtract ½ hour per week.

At chart time, Ursa Major is a very conspicuous constellation in the northeastern sky. Follow the curve of the Dipper's handle downward to locate the orange 1st-magnitude star Arcturus. Note Cor Caroli, near the center of curvature of the handle.

DEEP-SKY WONDERS

OF MORE THAN 100 Messier objects, only about four may be considered circumpolar at latitude 40° north, when an allowance of 10 degrees is made for horizon haze. Two of these, M52 and M103, barely fall within 30 degrees of the north pole, but M81 and M82, in Ursa Major, are easily visible every night of the year. Near them are two other fainter galaxies within the reach of small instruments; they are also shown on the accompanying 48-inch Schmidt photograph.

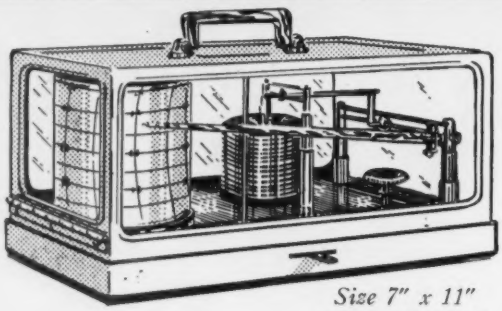
The bright spiral galaxy near the center is M81 in Ursa Major; above it is M82, and to the left is NGC 3077. A fourth galaxy, NGC 2976, is near the lower right corner. The three smaller systems are all at about the same distance from us as M81, which has recently been set at seven million light-years. North is above on this portion of a plate taken by the 48-inch Schmidt telescope. Mount Wilson and Palomar Observatories photograph.

Brightest and most famous of these four galaxies is M81. Too far north for the 100-inch telescope to reach, it has been photographed by the 200-inch telescope (see Plate 33, Sky Sets II). It is a closely wound spiral, NGC 3031, at $9^h\ 51^m.5$, +69° 18′ (1950 co-ordinates), and is 16′ by 10′ in size. At visual magnitude 8, it can be seen in a finder, but larger amateur reflectors are needed to bring out its full impressiveness.

Close by is the 9th-magnitude irregular galaxy M82, NGC 3034, at $9^h\ 51^m.9$, +69° 56′, and 7′ by 2′. It suffers by contrast with its more conspicuous neighbor, but were it by itself it would still attract attention.

NGC 2976, $9^h\ 43^m.2$, +68° 08′, is 3′ by 1′; with a visual magnitude of about 10, it is easily visible in a Skyscope reflector and well seen in a 2.4-inch Unitron refractor. Very similar is NGC 3077, $9^h\ 59^m.4$, +68° 58′, a 3′ by 2′ irregular galaxy which I have estimated as 10.0 visually at times.

Not far away lie two 11th-magnitude galaxies. NGC 2787, whose position is $9^h\ 14^m.9$, +69° 25′, is a barred spiral 2′ in diameter. A spiral of type Sb is NGC 2985, at $9^h\ 46^m.0$, +72° 31′. While the Shapley-Ames catalogue gives the diameter as 3′, I see this object as 1′ in a 6-inch. WALTER SCOTT HOUSTON



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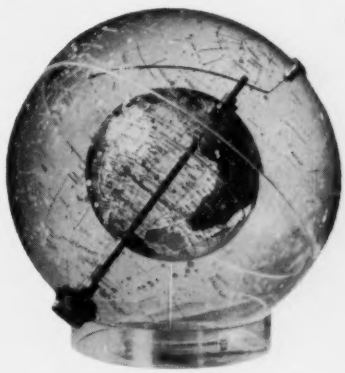

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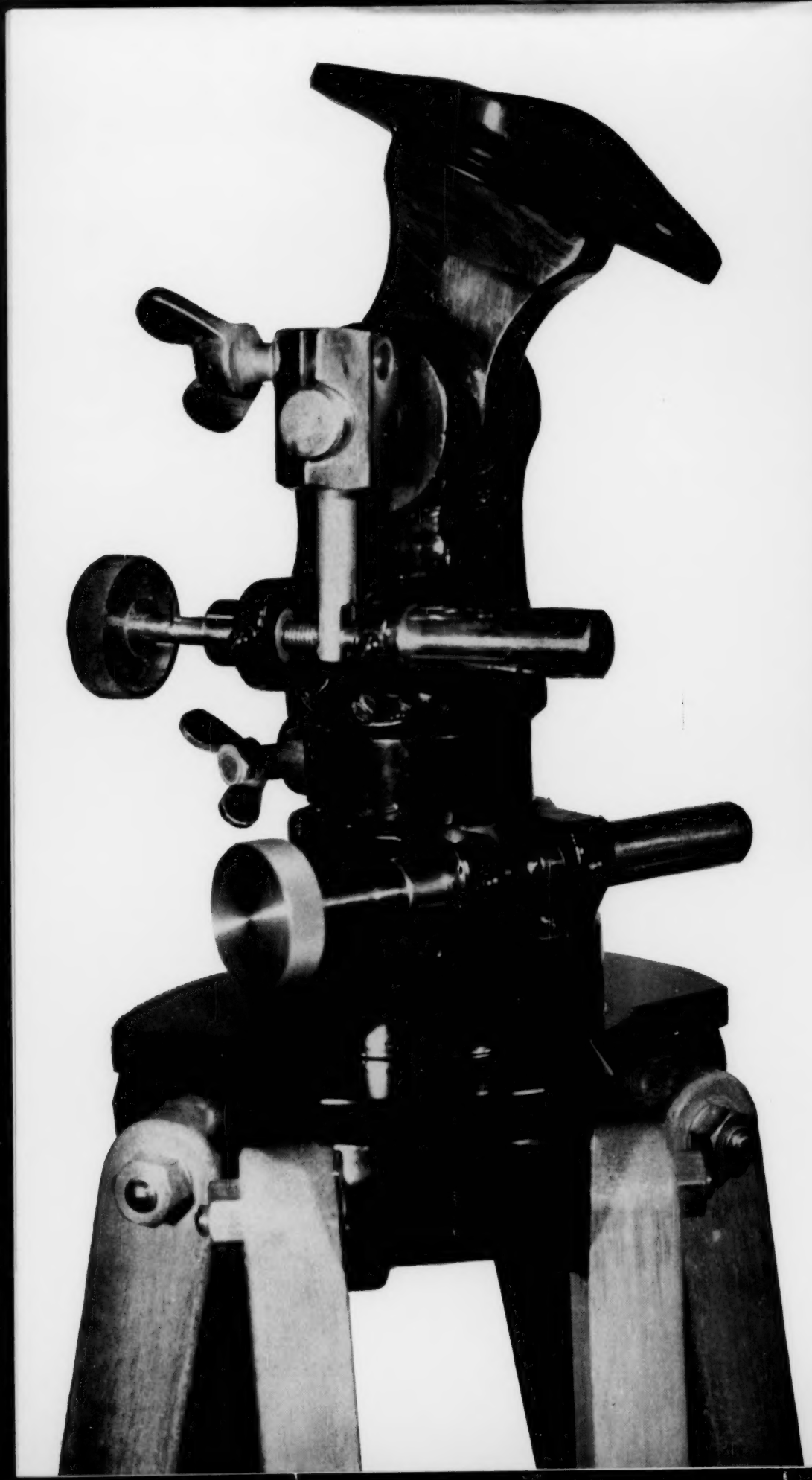

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(See pages 197 and 208)

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